ORIGINAL

ALTERNATIVE LINER DEMONSTRATION

Phase 5 Billings Regional Landfill

Prepared for:
City of Billings

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Great West engineering

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Introduction

Purpose and Scope

This document is intended to demonstrate that a proposed Phase 5 liner design for the Billings Regional Landfill, municipal solid waste license #113, meets the Design Criteria defined in Montana ARM 17.50.1204.

This investigation includes a review of hydrogeological and engineered site conditions, an evaluation of landfill leachate volume and chemistry, and an evaluation of the potential for leachate and landfill gas migration to affect the uppermost aquifer at the site. Previous studies of the facility include hydrogeological investigations, alternative liner demonstrations, alternative cover demonstrations, quality control/assurance documentation for both liners and covers, and semi-annual groundwater monitoring reports. This investigation includes information obtained from exploratory work conducted in February, 2012. That work included the drilling of three test borings and physical property analyses of 9 samples obtained via split-spoon sampler. The geotechnical report is included as Appendix A of this document.

Facility History

The Billings Regional Landfill is located at 5240 Jellison Road in the east ½ Section 29 and west ½ Section 30, Township 1 South, Range 26 East (Figure 1). It began accepting waste in about 1969, with an estimated annual waste acceptance of less than 45,000 tons. Steady population growth in the Billings area, along with the inclusion of additional towns and counties in the area, has resulted in an increase of waste disposal to the 227,700 tons accepted in 2011. With the advent of the revised solid waste regulations in 1994, more-highly engineered waste units have been designed and constructed at the facility. This also continued with the historical unlined waste areas (Phases 1 and 2) as they reached capacity. In 2007, the City began diverting Class IV waste from the main waste stream to a permitted area, and in 2008 they constructed a new lined cell in the Phase 3 area. Another new lined waste unit, Phase 4, was built in 2009. The facility operators previously received approval for an alternative liner for the Phases 3 and 4 expansions.

Site Characteristics

Climate

A summary of climatic data collected at the Billings airport is listed in Table 1. The complete daily records are available from the Desert Research Institute in Reno, Nevada. The annual average precipitation is 14.29 inches with a total average snowfall of 57 inches. The mean average daily high is 58.7 degrees Fahrenheit (F) and the mean daily low is 35.7 F.

Geology and Soils

The geology and soils are described in detail in Damschen & Associates (1991), EMCON (1996), and Tetra Tech (2007). The City of Billings landfill is located in dissected shale and bentonite deposits on the south side of the Yellowstone River, about five miles south of Billings, Montana. According to EMCON (1996), "The landfill is in a north-sloping drainage basin formerly occupied by ephemeral streams." These draws have been filled with municipal waste since the 1960s, and much of the existing waste lies atop unlined soil. Outcropping bedrock consists of Cretaceous-aged sedimentary rocks. EMCON (1996) reports that the facility and the area to the south are part of the Belle Fourche shale and the Greenhorn formation, which are dated to the upper Cretaceous. The Belle Fourche is described as dark grey, fissile, non-calcareous shale with interbedded bentonite beds that range from a few inches to several feet in thickness. This description fits the on-site exposures and well logs, although some reports describe the shale as claystone. The Tetra Tech (2007) report uses the term "claystone" throughout. Appendix A of this document has additional geological and soils information pertinent to the proposed waste unit.

Some localized landslide deposits and thin layers of colluvial soils are also present at the site (EMCON, 1996). These deposits have generally been excavated or covered during the deposition of municipal waste. Some of those younger deposits are still visible on the edges of the landfill.

A number of tests have been conducted by prior investigators, including laboratory-based evaluations of hydraulic conductivity and field tests of wells and piezometers. A summary of the laboratory assessments of hydraulic conductivity are included in Table 2, however the EMCON (1996) document from which some of the data are obtained does not include any analytical reports. The source of their summary values is not clear, but the data probably represent the results of all of the laboratory analyses and field investigations. It appears that only one sample of the bentonite was tested for hydraulic conductivity. Great West Engineering submitted an additional sample of the bentonite for analysis. EMCON/OWT, Inc. (2002) contains the hydraulic conductivity values of the colluvium (also referred to as "cover soil" and "CAH" in other publications) that was used as final cover for a portion of the Billings landfill. These soils were recompacted to 90 percent of standard Proctor moisture analysis and were analyzed by EMCON/OWT for permeability.

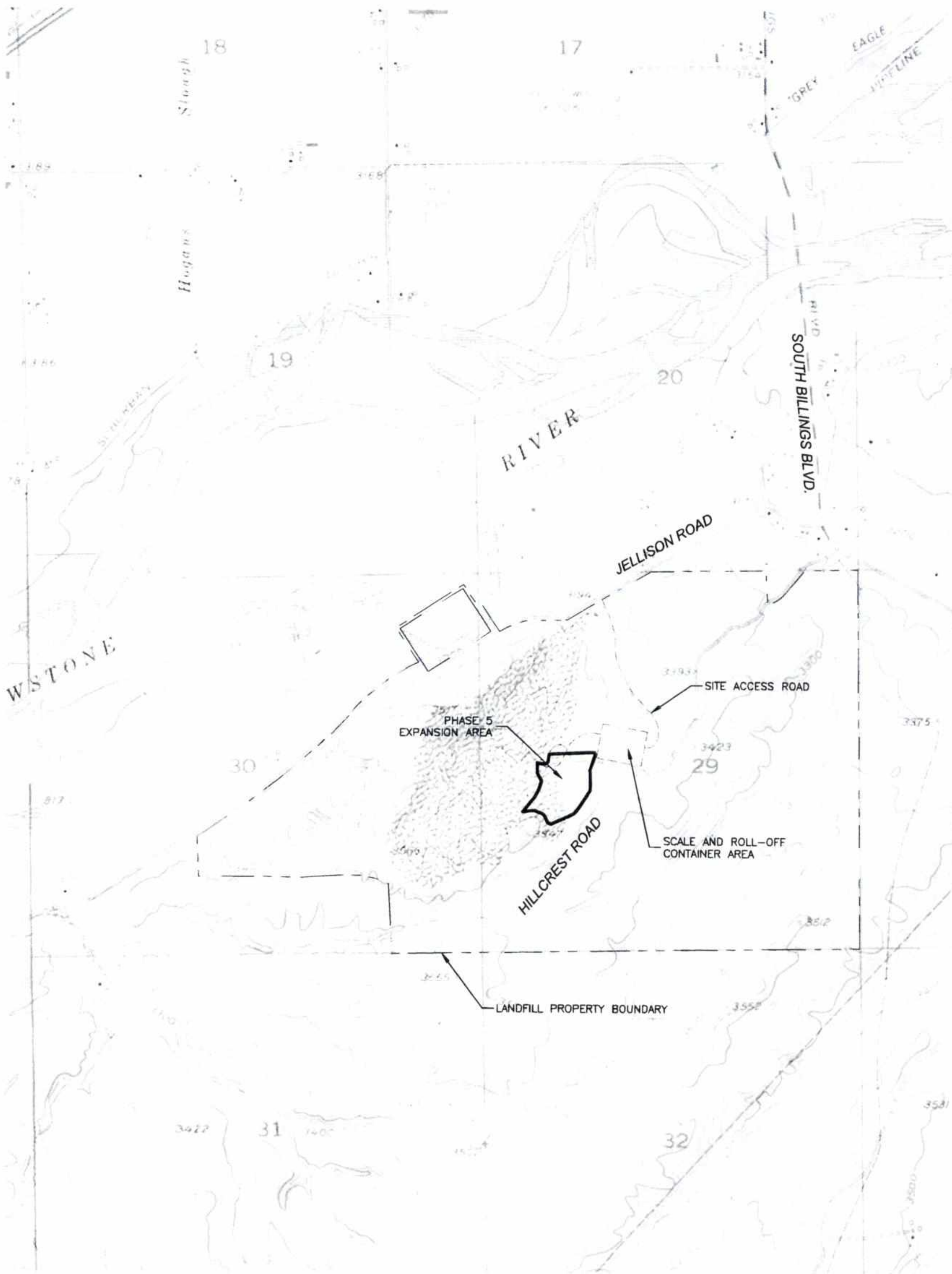

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Figure 1
Location Map

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Table 1 - Summary of climatic data from the Billings, Montana Airport

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	32.7	39	46	56.8	67.1	76.8	86.5	85.1	72.6	60.3	44.9	36	58.7
Average Min. Temperature (F)	14.2	19.5	25	34	43.4	51.7	58.3	56.8	47	37.3	26	18.2	35.9
Average Total Precipitation (in.)	0.74	0.61	1.07	1.8	2.26	2.08	1.1	0.85	1.28	1.14	0.72	0.64	14.29
Average Total SnowFall (in.)	9.8	7	9.8	8.9	1.7	0	0	0	1	4	6.5	8.3	57

Hydrogeology

Damschen & Associates (1991) and EMCON (1996) report the presence of three distinct hydrostratigraphic units at the Billings landfill. These are a shale bedrock unit, a colluvial unit, and an alluvial/landslide unit. The latter two are unconsolidated. Moisture migration in the shale bedrock unit is apparently controlled by fractures and bedding planes. The groundwater monitoring wells are located in shale, which probably belongs to the Cretaceous-aged Belle Fourche formation. The Greenhorn formation also occurs at the landfill, but overlies the Belle Fourche and its thickness at the facility has not been delineated. The colluvial and alluvial/landslide units host small quantities of locally-infiltrating water. The groundwater in these units tend to move laterally atop the shale bedrock unit, and, in places, infiltrates into that unit.

In general, recharge is thought to be local, with the shale bedrock unit being recharged in the low ridge on the south end of the landfill. Previous investigators have suggested that groundwater eventually discharges to the alluvial and fluvial deposits related to the Yellowstone River some 2,000 feet north of the facility. The groundwater flow in this unit appears to be toward the northeast with an estimated seepage velocity of 0.002 to 0.1 feet per day (ft/day), as reported by EMCON (1996). The horizontal flux through the unit was estimated presuming an average hydraulic conductivity of 0.1 ft/day, an average hydraulic gradient of 0.07. These calculations were based upon on-site slug tests, measured hydraulic gradients, literature values for porosity, and information provided in Reiten (1992). The EMCON report does not specifically reference the data used for these calculations, but appears to use low and high values to establish the ranges presented. Those previous investigators also suggest that the groundwater flow south of the Phase 1 and 2 areas is toward the south.

The most-recent investigation (Appendix A; Figure 2) did not reveal the presence of groundwater within 50 feet below the existing surface, to an elevation of approximately 3,320 feet MSL in the boring dubbed DH-1. Groundwater flow maps imply that groundwater should occur at an elevation of about 3,330 feet MSL. Likewise, boring DH-3 was completed to a depth to about 3,368 feet MSL, with groundwater being mapped at elevations between 3,400 and 3,450 feet MSL. Groundwater is mapped at an elevation of about 3,300 feet elevation near boring DH-2, which was drilled to a depth

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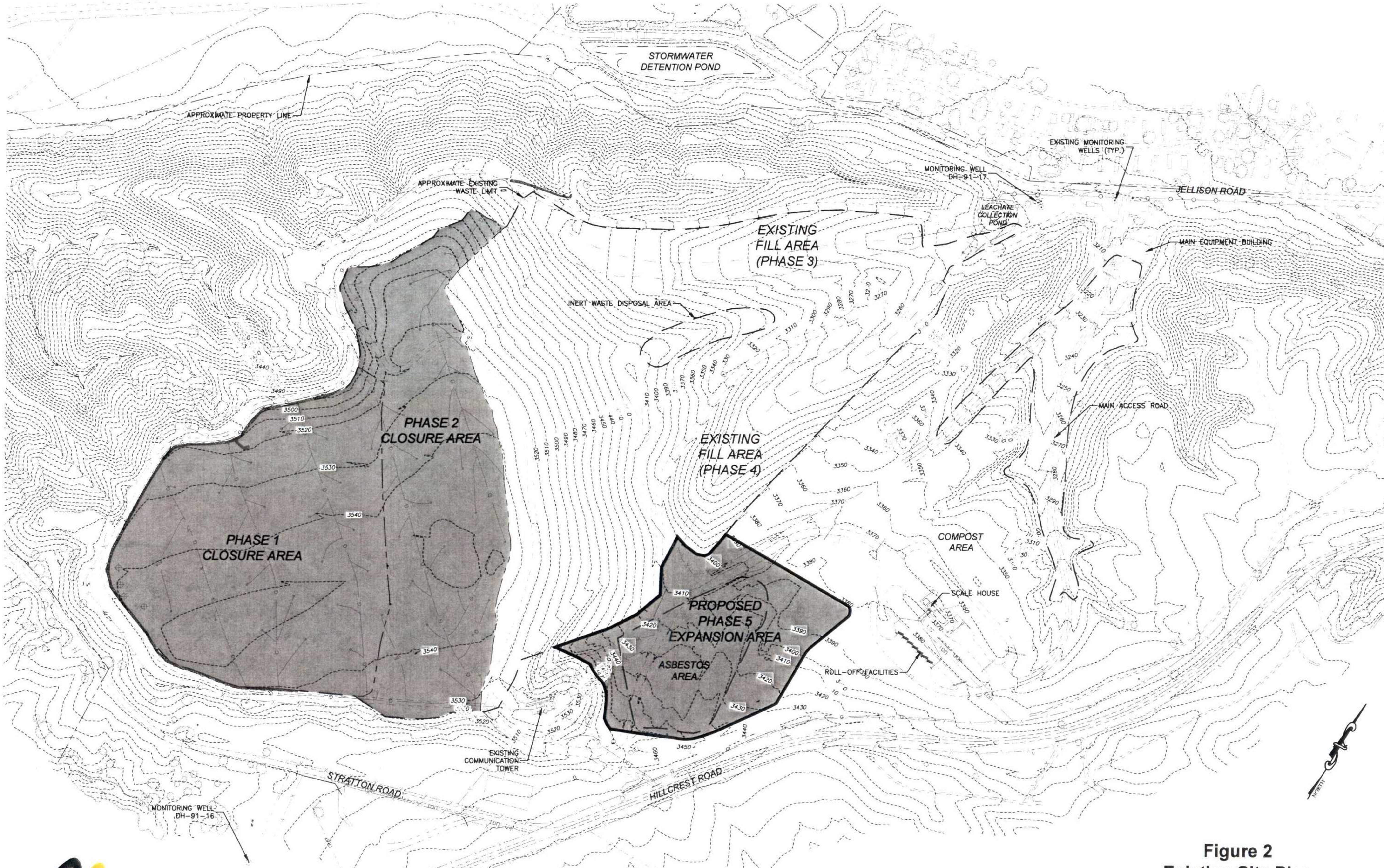

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BASE TOPOGRAPHY PREPARED BY MONTANA AERIAL PHOTO, INC. DATE OF AERIAL IS 8/31/2004. TOPOGRAPHY IN LANDFILL CELL AREA UPDATED JANUARY 2012.

0 200 400
SCALE IN FEET

Figure 2
Existing Site Plan

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of about 3,310 feet MSL. It is possible that boring DH-2 did not achieve sufficient depth to encounter groundwater. However, borings DH-1 and -3 would have encountered groundwater if it occurred as the existing maps indicate. The nearest groundwater monitoring well (DH-91-16) is over 2,500 west-southwest of boring DH-3. The water level in that well is reported to be about 3,464 feet MSL.

If groundwater was contiguous across the site, some evidence of it should have been discovered in the 2012 site investigation. The subsurface consists of exclusively fine-grained material, most of which does not transmit water efficiently. Water could possibly move through fractures or bedding planes, but the recent drilling indicates that those structures are commonly filled with bentonite. It is highly unlikely that groundwater underlies the entire facility in anything resembling a contiguous aquifer. More likely, groundwater seeps through preferred pathways that are difficult to predict.

The existing information suggests that groundwater is contained within either locally-derived, unconsolidated deposits or the Belle Fourche shale. Even though the groundwater is presumed to have a local recharge source, the quality is very poor, owing to the nature of the water-bearing units. The results from groundwater monitoring at the facility include chloride values from 100 to nearly 1,000 milligrams per liter (mg/L), sulfate concentrations in excess of 13,000 mg/L, and specific conductance values approaching 20,000 micromhos per centimeter. If the value of the groundwater to humans is to be taken into consideration, then the potential for any application is very low.

Perhaps the most telling evidence for the argument against the presence of any viable groundwater resources is the paucity of wells in the Belle Fourche shale. There are dozens of residences off of Hillcrest Road, within two miles of the landfill, and none of them have wells. The only wells noted in the GWIC database are shallow ranch wells located in the bottom of a coulee. We consider the Belle Fourche shale to be an aquitard.

Phase 5 Soil Properties

Three test borings drilled within and proximal to the Phase 5 waste unit revealed the presence of mostly shale belonging to the Belle Fourche formation. Bentonite occurred in scattered locations as fracture fillings and thin seams. Two thin beds (two feet or less) of bentonite occurred in the hole designated as DH-3. That test boring was completed to a depth of 90 feet and was situated at the south end of the facility, just outside of the lined waste cell limit. Those beds, if they continue northward, will be excavated over most of the Phase 3 unit.

The moisture content of the samples ranged from 6.5 to 10.6 percent by weight, with one exception (Table 3). The interval at 15-20 feet in DH-1, which was drilled in the northern part of the cell base, had a moisture content approaching 20 percent. That Table 2 - Summary of Hydraulic Conductivity values of subsurface and surface soils at the City of Billings, Montana landfill.

Table 2 - Summary of Hydraulic Conductivity

Location	Depth (feet)	Material	Condition*	Hydraulic Conductivity (cm/sec)
DH-1 (Phase III cell)	26 - 29	Claystone	Remolded	3.80E-09
DH-2 (Phase III cell)	16 - 19	Claystone	Remolded	1.90E-09
DH-3 (Phase III cell)	15 - 18	Claystone	Remolded	1.90E-09
DH-7 (Phase III cell)	22 - 25	Claystone	Remolded	3.10E-09
Average of 35 Samples, Undisturbed From Final Cover	Surface	Colluvium (CAH)	On-Site Recompacted	6.50E-08
DH-2	2.2 - 12.2	Clay	Remolded	2.00E-04
DH-6	2.4 - 12.4	Clay	Remolded	6.00E-07
DH-6	8.0 - 8.5	Clay	Undisturbed	1.00E-06
DH-1	22.6 - 32.1	Shale	Remolded	5.00E-07
DH-5	22.5 - 24.0	Shale	Undisturbed	2.00E-05
DH-5	33.3 - 40.3	Shale	In-situ	3.00E-06
DH-90-3	43.5 - 44.0	Bentonite	Undisturbed	4.00E-09
DH-90-4	30.0 - 40.0	Sandy Mudstone	In-situ	8.00E-07
DH-90-5	40.0 - 50.0	Shale	In-situ	4.00E-07
Cell Exposure	Surface	Bentonite	Remolded	5.44E-10
32 Unknown Locations	0.5 - 1.67	Various	In-situ	1.97E-06 - 6.38E-03
Unknown	unknown	Shale	Various	4.00E-07 - 3.00E-06
Unknown (same as DH-90-3?)	unknown	Bentonite	Various	4.00E-09

*Indicated samples remolded to 90 percent of optimum moisture/density;

In-situ data from slug tests or Guelph permeameter tests performed in indicated well.

Table 3 - Summary of soil properties from the 2012 geotechnical investigation of the proposed Phase 5 unit, Billings Regional Landfill

Test Boring/ Depth	Percent Sand	Percent Fines (passing #200)	Percent Silt	Percent Clay	Liquid Limit	Plastic Limit	Plasticity Index	Maximum Dry Density (lb/ft^3)	Optimum Moisture (percent weight)	Percent Moisture (percent weight)	Saturated Hydraulic Conductivity (recompacted to 95 % of standard Proctor; cm/sec)	Saturated Hydraulic Conductivity (core sample; cm/sec)	Porosity
DH-1 (15-15.9')	3	97	63.8	32.9	43	19	24						
DH-1 (15-20')								102.9	19.6	19.7	4.64E-07		0.410
DH-1 (25-25.7')	2	98	62.3	35.4	44	18	26						
DH-1 (25-30.7')										9	5.94E-09		0.258
DH-1 (35-35.5')	1	99	52.2	47	59	19	40						
DH-1 (35-40')										10	7.12E-09		0.270
DH-1 (45-45.4')	9	94	37.7	55.3	67	20	47			10.6	2.56E-09		0.279
DH-2 (20-20.4')	3	97	60.3	36.7	43	19	24						
DH-2 (20-25.4')										9.9	7.87E-09		0.288
DH-2 (35-35.4')	7	93	47.8	45.3	45	18	27			7.3	5.89E-09		0.259
DH-3 (55-60')	5	95	57.3	38	42	19	23			6.5		3.83E-11	0.142
DH-3 (70-75')	2	98	59.2	39.2	48	20	28			7.3		7.16E-11	0.186
DH-3 (85-90')	1	99	68.2	31	55	22	33			7.6		2.19E-11	0.190
mean values	3.7	96.7	56.5	40.1	49.6	19.3	30.2			9.8	1.15E-08	4.39E-11	0.254

area had been used as a borrow source for daily cover, is relatively flat, and receives moisture from a large portion of the proposed waste cell area. The higher moisture content is presumably due to surface infiltration in disturbed soil.

The shale consists of 94 to 99 percent fines (passing the -200 sieve). One sample, from DH-1, underwent moisture-density relationship testing and was found to have a maximum dry density of 102.9 pounds per cubic foot and an optimum compaction moisture content of 19.7 percent.

Four soils samples from test boring DH-1 and two samples from boring DH-2 were recompacted to 95 percent of standard Proctor and tested for saturated hydraulic conductivity. The results ranged from 2.56 x 10-9 to 4.64 x 10-7 centimeters per second (cm/sec). However, the fastest value was produced by a sample from 15-20 feet below the surface in DH-1. All of the other recompacted samples exhibited hydraulic conductivities in the 10-9 cm/sec range. Three core samples from boring DH-3 also underwent testing for hydraulic conductivity. Those undisturbed samples returned values in the 10-11 cm/sec range. Please note that the "core" samples were drilled cores, not driven split-spoon samples. We feel that the cored samples are perhaps the best reflection of the physical properties of the shale because they were not subjected to any additional compaction or other physical manipulation during the collection process.

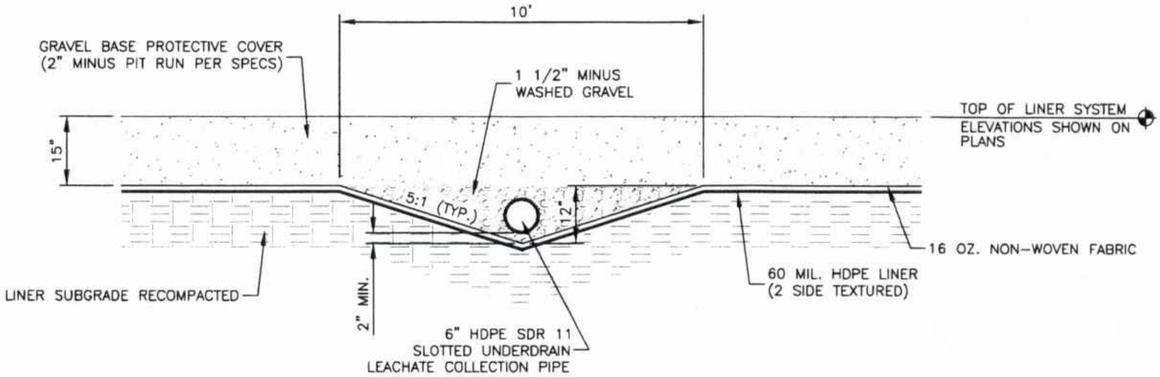
The Phase 5 footprint area is the source of borrow material used for the construction of the Phase 2 closure. The material was tested extensively during that process, with the analyses including nearly 60 sieve samples, seven hydrometer grain-size tests, and over 100 in-place density tests. The in-place density tests, however, are not representative of in-situ material because the subject soils were not highly recompacted. Analyses conducted on the material prior to placement was completed on samples recompacted to 85 percent of standard Proctor values, and resulted in bulk densities on the order of 87 pounds per cubic foot (pcf) or 1.40 grams per cubic centimeter (g/cm3). The hydraulic conductivities of two samples recompacted to 85 percent of standard Proctor values were 3.4 x 10-5 and 8.0 x 10-6 cm/sec. The average of five laboratory-tested composite samples of the cover material recompacted to 85 percent of standard Proctor value was 1.38 g/cm3, or 87.4 pcf. The recompacted saturated hydraulic conductivity of those same samples ranged from 5.4 x 10-6 to 2.5 x 10-4 cm/sec.

Again, the sample analyses from the Phase 2 closure construction testing either do not represent in-situ, undisturbed soil, or they represent tests conducted at a considerably lower recompaction rate. The average dry bulk density value of the 2012 testing of 1.65 g/cm3, when compared to the 1.38 to 1.40 g/cm3 value of the construction soils, appears reasonable. Also, the saturated hydraulic conductivity of the Phase 5 testing shows results consistently lower than those produced by the construction soils.

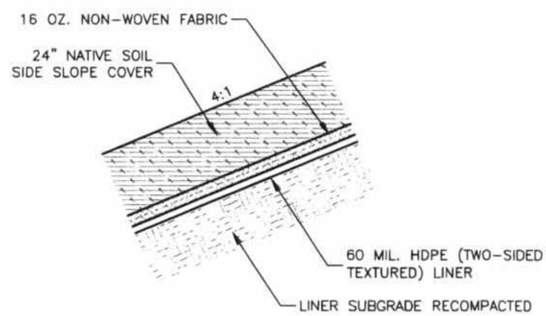
Liner Design

The unit covers about 15 acres, with about 20 percent of the cell comprising side slopes. The proposed liner (Figure 3) on the sideslopes consists of, from top to bottom, 24 inches of native soil cover, a 16-ounce non-woven fabric, 60 mil HDPE liner with two-sided texture, and native soil. The base will have 16 inches of gravel as protection for the liner. Native soil that is not suitable for compaction will be excavated to a depth of six inches and replaced with appropriately-compacted soil. The sides of the waste unit will generally be a 4:1 slope and the slope of the base range from 6 to 10 percent. The dimensions of the Phase 5 waste unit are shown on Figure 4. The cell will be filled with five- to ten-foot lifts of waste to a full thickness of 125 feet.

Phase 5 will essentially serve as the side of an adjoining cell that will be designed in the future. The Phase 5 unit will ultimately have about 125 feet of waste, daily cover, and intermediate cover.



TYPICAL BASE LINER/LEACHATE COLLECTION LATERAL



TYPICAL SIDE SLOPE LINER DETAIL

NOT TO SCALE

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Figure 3
Typical Base Liner/Leachate Collection Lateral Cross Sections

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Design Criteria Evaluation

Introduction

The Administrative Rules of Montana 17.50.1204 (1) states that "An owner of operator of a new Class II or Class IV landfill unit or a lateral expansion of of an existing Class II or Class IV landfill unit may construct it only if the owner or operator has obtained department approval of a design that either: (a) ensures that the concentration values listed in Table 1 of this rule will not be exceeded at the relevant point of compliance, or, (b) utilizes a composite liner and a leachate collection and removal system that is designed and constructed to maintain less than a 30-cm depth of leachate over the liner." The proposed liner system at the Billings facility will have a leachate collection and removal system, but the liner design does not meet the definition of "composite liner" outlined in ARM 17.50.1202 (5). That definition states that a "Composite liner" means a system of two components, including a flexible membrane underlain by at least two feet of clay recompacted to a hydraulic conductivity of no less than 1×10^{-7} cm/sec. The base proposed to underlie the 60-mil HDPE liner at the facility is designed to be either appropriately-compacted native soil or six inches of recompacted native soil, therefore, the owner or operator must ensure that the conditions of 17.50.1204 (1) (a) are met. The conditions of rules differ from the previous regulations, in that the old rules prescribed a specific set of design criteria that would be equivalent to those prescribed in the federal Sub-Title D rule. With that language absent, it is the responsibility of the owner or operator to insure that the constituents in Table 1 will not be exceeded in groundwater at the relevant point of compliance.

The objective of this evaluation is to demonstrate that the constituents listed in Table 1 will not be exceeded at the relevant point(s) of compliance at the Billings Regional Landfill. The points of compliance, for the purpose of this investigation, are assumed to be the down-gradient edge of the licensed facility. The limit of Table 1 concentrations in groundwater are defined by the limits set in the Montana Department of Environmental Quality Circular 7 for groundwater.

The geology of the site is such that leachate would be unlikely to migrate very far or very fast. Well-compacted shale with a 30 to 55 percent clay fraction cannot be considered as a potentially robust aquifer. We feel, consequently, that gaseous diffusion would appear to be the most probable process by which contaminants could reach groundwater. Previous analyses for Phases 3 and 4 have demonstrated that fluid migration through the shale bedrock is not a viable pathway for contaminants for exceptionally long periods of time.

Background and Assumptions

An investigation of chemical migration through saturated and unsaturated media needs to take into account a rather large number of real and potential conditions. Among those elements are: volume and chemical character of leachate; potential head of the leachate over the liner; structural competency of the flexible membrane; permeability and attenuation characteristics of the liner system, and; permeability and attenuation characteristics of the soil between the liner system and the uppermost aquifer. Some of these elements are impossible to measure in a system that has not been constructed, therefore, one must rely on information available in published literature.

In the case of the Billings Regional Landfill landfill, extensive studies of the soils and groundwater have already been conducted. The subsurface conditions can be reasonably well characterized and, in many instances, quantified. The geotechnical study completed for this demonstration (Appendix A) provides important physical characteristics of the soil and groundwater within and proximal to the Phase 5 unit.

Characteristics of Liner System Components

The liner system at the Billings Regional Landfill, as outlined above, includes a flexible membrane liner, an underlying native or recompacted clay layer, and a leachate collection and removal system. In addition to the engineered system, some investigators (Rowe and Brachman, 2004; Lake and Rowe, 2005; Rowe, 2005) suggest that the protective value of natural or engineered soil between the liner and the top of the uppermost aquifer is an integral part of the system. In the case of this investigation, that attenuation layer consists of the naturally-occurring sediments in the Oligocene-aged deposits underlying the facility.

HDPE Flexible Membrane

For the purposes of this investigation, the 60-mil HDPE flexible membrane is assumed to be well-placed, with an average of one hole having a radius of 0.00564 meters (or an area of 98.5 square millimeters; 0.153 square inches) per acre, which, according to Rowe and Brachman (2004), is a reasonable assumption. The permeability characteristics of the HDPE membrane are assumed to be similar to those described by Rowe and Brachman (2004), Rowe (2005) and Lake and Rowe (2005).

Undisturbed or Recompacted Native Soil

The native soil proposed for the barrier layer beneath the flexible membrane liner (FML) is assumed to have a hydraulic conductivity no greater than 1 x 10-7 cm/sec, which is the regulatory standard for a recompacted soil liner. One of the four soil samples taken for this study did not meet that standard when recompacted to 95 percent of Standard Proctor compaction. However, the other three samples returned values of 2.56 to 7.12 x 10-9 cm/sec. The geometric mean of those four values is 1.49 x 10-8 cm/sec.

The data from both Table 2 and 3 supports the use of 1 x 10-7 cm/sec as a conservative value. Four samples of recompacted claystone from the base of Phase 3 averaged 2.68 x 10^{-9} cm/sec and an average of 35 samples obtained from the final cover used for a large portion of the landfill yielded an average recompacted hydraulic conductivity of 6.5 x 10^{-8} cm/sec.

Attenuation Layer

The attenuation layer for modeling purposes is accepted to be the native soil lying between the base of the engineered liner and the top of the uppermost aquifer. In this case, that thickness is problematic, because no groundwater was detected at the elevations where it is mapped. The absence of groundwater in the Phase 5 area is discussed in a previous section.

We also note that a test boring drilled in the lower end of the Phase 3 cell in 2007 (DH-8; TetraTech, Inc., 2007) was terminated at depth of 60 feet, at an elevation of 3,171 feet MSL. No groundwater was encountered in that test boring. A groundwater monitoring well about 900 feet northeast of that location (well DH-91-17) is reported to have a static water level of about 3,190 feet MSL. That well is completed in "dark gray shale" noted as the Frontier formation. More-recent geological mapping has confirmed that the rock is considered to be the Belle Fourche formation. Groundwater maps indicate that groundwater should have been detected in test boring DH-8 at an elevation of about 3,225 feet MSL.

The nearest water well registered with the Montana Ground Water Information Center for domestic use lies about three-quarters of a mile to the west-southwest of the landfill, in Section 31 (the "Stratton" well, GWIC #94193). That well is over 1,200 feet deep and appears to traverse the Belle Fourche formation, the Mowry shale and the Thermopolis shale into either the Fall River sandstone or the Kootenai formation. It is reported to be a flowing well.

Clearly, groundwater does not underlie the entire facility in a single discrete aquifer within 1,000 feet of the ground surface. The "Stratton" well west of the landfill taps a water-bearing zone that can be considered as a regional aquifer. As noted in the previous section discussing the site hydrogeology, recharge in the colluvium, landslide deposits and the shale is considered to be local. Phase 5 lies near the top of a low ridge and is underlain by the Belle Fourche shale. The fact that groundwater is not found everywhere across the unit or the site is not unusual. Precipitation is relatively low, the permeability of the substrate is exceptionally low, interstices and fractures in the substrate are commonly filled with bentonite, and weathered bedrock tends to form a clay-rich regolith that is not able to transmit large volumes of moisture.

Given these conditions, the thickness of the attenuation layer can be viewed in a number of ways. With respect to gaseous diffusion, the nearest groundwater that could impact human health and safety lies over 1,000 feet below the surface. From the perspective of the groundwater monitoring system, however, groundwater beneath the waste unit that might migrate to a point of compliance needs to be considered. But, there is no shallow groundwater underlying the Phase 5 site at the depths indicated by the monitoring reports submitted to the Department. Therefore, an alternative approach is required. Lacking a clear presence of shallow groundwater, then, we assume that the attenuation layer would comprise the material between the base of the liner system to a depth equal to that of the highest groundwater elevation found at the down-gradient point of compliance. The highest elevation of groundwater at the down-gradient side of the facility is about 3,194.5 feet MSL. The lowest point of the base of the Phase 5 unit will be at an elevation of approximately 3,375 ft MSL. Therefore, the attenuation layer for the model is assumed to be 180 feet.

Aquifer Characteristics

Groundwater occurs in relatively thin zones within three different geological materials. For the purposes of this investigation, only the groundwater in the Belle Fourche shale will be considered, since the other two potential water-bearing formations overlie the shale.

As noted by previous investigators (Damschen & Associates, 1991; EMCON, 1996), groundwater in the shale does not occur in a discrete formation beneath the entire facility. The existing groundwater monitoring network appears to tap at least one water-bearing zone related to the Belle Fourche shale. Water migrates through fractures and/or bedding planes over a zone less than three feet thick.

Landfill Leachate Characteristics

Landfill leachate chemistry is dependent upon the nature of the waste, climatic influences, and the age of the waste (Klinck and Stuart, 1999; Bonaparte and others, 2002). Nationally, municipal solid waste landfill leachate from landfills constructed after 1990 is slightly acid, with very high specific conductance (>3,700 umhos/cm) and high total dissolved solids (>2,700 milligrams per liter; mg/L; Bonaparte and others, 2002).

Inorganic Constituents

The predominate dissolved solids are typically chloride, sulfate, calcium, magnesium and sodium (Klinck and Stuart, 1999; Bonaparte and others, 2002),. Heavy metals occur in post-1990 landfills typically in excess of maximum contaminant levels (MCLs) established by the U.S. EPA and state agencies. For example, the average concentration of arsenic in post-1990 landfill leachate for 22 U.S. landfills was 23 micrograms per liter (ug/L; Bonaparte and others, 2002). The Montana Human Health Standard for arsenic in drinking water is 10 ug/L. The average lead concentration in leachate is on the order of 15 ug/L (Bonaparte and others, 2002), which equals the Montana Human Health Standard in groundwater. Samples of leachate collected from a landfill in north-central Montana in 1995 and 1997, within three years of the first acceptance of waste, contained sulfate (130 and 210 milligrams per liter; mg/L), chloride (7 and 19 mg/L), nitrate (1.39 and 1.18 mg/L) and iron (0.03 and 0.07 mg/L). We consider these analyses to be somewhat atypical because they most likely reflect a fair amount of dilution resulting from the relatively thin waste cover. The sample from 1995 represents water that collected while there was no waste on a large portion of the cell. The later sample was collected after a large precipitation event when there was less than four feet of total waste cover on the cell. Very little leachate was produced in the year between the collection dates of the two samples.

Certain organic compounds can capture inorganic ions and move them in solution through soil, but most dissolved polar ions are susceptible to at least some level attenuation in the vadose zone. The Billings facility is underlain by soils dominated by fine-grained material, of which clay constitutes an average of over 25 percent by mass (Table 1) and for which the mean plasticity index is over 55. While the estimated porosity is fairly high (Table 1), the high percentage of fines and generally poor sorting of the sediments will lead to a fairly high tortuosity (Fetter, 1988), increasing the attenuation factor.

Volatile Organic Compounds

Bonaparte and others (2002) report average concentrations of volatile organic compounds (VOCs) to be wide-ranging, with most not detected at over 50 percent of landfills investigated. Klett and others (2005) report a wide variety of concentrations of VOCs in samples of leachate from facilities in Wisconsin, ranging from nearly 90 percent of 49 landfills reporting the presence of toluene to two percent reporting the presence of bromomethane and trans-1,2-dichloroethene. It is important to note that the values reported by Klett and others (2005) represent lined facilities dating back to 1985, so there is a possibility that some mixed waste landfilling occurred at some sites.

Rowe (2005) has noted that ions and compounds with larger molecular diameters are generally actively attenuated from landfill leachate by clay barriers and/or attenuation layers. Polar ions are adsorbed onto substrate particles or simply prevented from migrating due to the tortuosity and small pore matrix of clay barriers and soils. In cases where leachate successfully migrates through a barrier system, the larger-diameter ions and compounds are adsorbed by the substrate particles or otherwise attenuated. In addition, leaks in a reasonably well-constructed geomembrane will tend to spread over a relatively large area rather than penetrate the clay barrier at specific leak points that would result in stochastic flow. That process essentially reduces the potential head and increases the surface area of the infiltration. In short, unless a barrier system suffers from a serious failure at a point of high leachate head, the potential for significant quantities of leachate to breach the liner and migrate to a water-bearing stratum is relatively low. Conversely, poorly-constructed membranes that have numerous hole and wrinkles are susceptible to considerable leakage, particularly if clogging of the drainage layer occurs because of insufficient thickness and/or permeability.

Leachate Volume

The Billings facility has a leachate collection system that drains 18 acres in Phases 3 and 4. The facility recirculated approximately 50,000 gallons of leachate from their collection pond in 2011. That leachate was applied back onto Phases 3 and 4, where the bulk of the gas extraction is occurring. However, moisture from the gas-extraction plant is being applied to the Phase 3 unit via a horizontal injection well. The gas-extraction plant operator estimates that the process injected some 120,200 gallons of moisture from the concentrator into Phase 3. Given that the leachate collection pond has received only 50,000 gallons of leachate, along with the potential for summertime evaporation from the pond, the leachate production appears to be a net loss. A temporal aspect of this process may come into play, however. The condensate may be distributed throughout what was relatively dry waste. The Landfill Gas Condensate and Leachate Recirculation Plan (Wenck Associates, Inc., 2010, unpublished) contains information regarding the waste moisture content in Phases 1 and 2. The authors of the plan assume a default moisture content value for municipal solid waste of 15 percent by weight. The test data show that the actual moisture content varies considerably throughout the vertical profile of the Phase 1 and 2 areas, with some samples returning moisture contents below six percent. Much of the condensate is apparently being absorbed by waste, but the cells are still producing considerably more leachate than they did prior to the injection of the condensate. The operators of the facility report that Phases 3 and 4 produced less than 10,000 gallons of leachate annually prior to the construction of the gas extraction plant (pers. comm., Barbara Butler, City of Billings Environmental Coordinator). As of yet, the moisture being recirculated in Phases 3 and 4 have not yet reached a point of equilibrium.

Landfill Gas Characteristics

The Billings Regional Landfill has complied with the EPA and Montana requirements regarding the estimation of the production of gaseous non-methane organic chemicals (NMOC). The last NMOC testing was undertaken in 2007, and the data were applied to the EPA LandGEM model. The model uses average analytical values generated from multiple sampling points across the facility. That model assumes that NMOC concentrations constitute 0.178 percent by mass of total landfill gas produced. The results of the 2007 model predicted the total mass of landfill gas produced in 2011 to be 23,620 tons (1.719 x 107 cubic meters). The model also predicted an NMOC mass of 42.1 tons (10,680 cubic meters).

We feel it important to point out that the values produced by the LandGEM model may be gross over-estimates of gas production. The US Environmental Protection Agency, which produced the LandGEM model, also requires that landfills of a certain minimum size report the potential production of greenhouse gases, including methane, on an annual basis. The spreadsheet calculators provided for the agency provide a standard process by which facility operators may calculate methane production. Those spreadsheet results are, in this case, based on exactly the same waste-in-place masses as the LandGEM model. However, they produce very different results. The LandGEM model predicts that the Billings Regional Landfill is producing over 21,000 metric tons of methane annually. The Greenhouse Gas Reporting (GHG) process estimates that value to be about 4,000 metric tons. We have chosen to use the LandGEM values in an attempt to be conservative in our modeling inputs. If the GHG values are correct, we have over-estimated the production of landfill gas and its related NMOC constituents by an order of magnitude.

Additional details of the landfill gas characteristics are discussed further in a subsequent section of this document.

Modeling

General Background and Assumptions

The 2010 changes in Montana regulations have demanded a somewhat different approach to the evaluation of alternative liners. ARM 17.50.1202 (5) provides for a "prescriptive" liner design and conditions for the implementation of a leachate collection system. In the case of the Billings Regional Landfill, the proposed liner design differs with the prescribed liner primarily in that the recompacted soil base is replaced either by native soil or six inches of recompacted soil. While the design includes an HDPE liner of the appropriate thickness and a leachate collection system that will minimize standing head on the liner to 30 centimeters (cm; one foot), the barrier layer below the geomembrane does not meet the two-foot thickness requirement. Therefore, the conditions of ARM 17.50.1204 (1)(a) must be met. Those conditions require that the owner/operator ensure that the concentration values listed in Table 1 will not be exceeded at the relevant point of compliance in the uppermost aquifer. In order to demonstrate that the proposed liner will meet those conditions, the DEQ guidance proposes a three-step approach to the investigation and regulatory approval of an alternative liner. If the proposed liner system is a composite system that includes an approved geomembrane (flexible membrane liner) and leachate collection system, then the liner system must be shown to be as effective as the prescribed system at its base with regard to transmission of the ARM 17.50.1200 Table 1 constituents. If that cannot be demonstrated successfully, then further investigations must be undertaken to demonstrate that the Table 1 constituents will not exceed regulatory standards at the relevant point of compliance within a period of time of at least the life of the landfill plus its minimum post-closure period of 30 years.

The geology of the attenuation layer involves shale having an average porosity of 0.254 and a moisture content of 9.8 percent (Table 3). The geometric mean of all the hydraulic conductivity tests is 1.73 x 10-9 cm/sec. Using those assumptions, the seepage velocity (based on a hydraulic gradient of unity) would be 6.81 x 10-9 cm/sec, or 1.931 x 10-5 feet per day (ft/day). A very simple time-of-travel calculation through the 180-foot thick attenuation zone, then, yields a value of over 25,500 years. However, since moisture appears to travel along preferential flow paths, that value is not realistic. It still offers a sense of the hydraulic conditions in the attenuation layer. With a porosity of 0.254 and a moisture content of about 10 percent, even relatively small volumes of water traveling along bedding planes would require considerable periods of time to saturate any part of the attenuation layer. This concept is supported by the demonstrated absence of water-bearing zones over most of the facility.

We are of the opinion that a much greater risk to groundwater is the diffusion of VOCs from landfill leachate and, even more critically, landfill gas. Fluid can only move via advection through defects in the liner or degradation of the geomembrane over time and, in either event, it still has to migrate through many tens of feet of clay-rich soil. Gases, however, can diffuse through intact geomembranes, recompacted clay liners, and naturally-occurring soil (Carpenter and others, 1993; Hoffman and Chiarappa, 1998; Rowe and Brachman, 2004; Lake and Rowe, 2005; Stark and Choi, 2005; Rimal and Rowe, 2009).

Based on all of the above criteria and observations, we selected the POLLUTE (T) V. 7 software to model the potential migration of contaminants. The model has a 15-year history, and functions on the integration of data to develop rates of flow and contaminant concentrations based on diffusion.

Model Input Values

The following section describes and qualifies the POLLUTE v.7 inputs. We developed two models, one for the composite liner as described in ARM 17.50.1402 and one for the proposed design. Many aspects of both models are the same, such as initial VOC concentrations, attenuation layer characteristics, etc. Differences between the two models are called out in the descriptions for each input. However, prior to describing the inputs, a consideration of some bases and rationale for certain input values is warranted.

Perhaps the most critical element of a diffusion model involves the chemical of concern (COC). The source concentration is an important aspect of the model, but the diffusivity of the selected COC across a given barrier is also critical. The following discussion presents the reasoning for the selection of certain model inputs specifically regarding the COC.

Table 1 of ARM 17.51.1204 presents a group of VOCs that constitute COCs for which maximum contaminant limits (MCLs) cannot be exceeded. Perhaps the most logical target in that list for estimation of concentrations at the relevant point of compliance (RPOC) is vinyl chloride (VC). Vinyl chloride has a low maximum contaminant level (2 ug/L), a low minimum reporting level (0.5 ug/L) and considered to be a carcinogen of significant risk. However, vinyl chloride is rarely, if ever, introduced to MSW as a compound because it is highly volatile, difficult to contain and very flammable. More commonly, vinyl chloride is a biodegradation product of other VOCs. Tetrachloroethene (PCE) and trichloroethane (TCA) are well-known sources for VC, as they can be the parent chemicals that degrade to 1,1,1-trichloroethene (TCE), cis- and trans-1,2-dichloroethene (c-1,2-DCE, t-1,2-DCE), 1,1-dichloroethene (1,1-DCE), to VC. Soltani-Ahmadi (2000) lists EPA-derived averages of various VOCs measured in landfill gas samples in the US, noting concentrations of PCE (1.19 ppmv = 10.4 ug/L, at 48 sites), TCE (0.381 ppmv = 13.1 ug/L, at 48 sites), t-1,2-DCE (0.051 ppmv = 7.7 ug/L, at one site), DCE (0.092 ppmv = 3.7 ug/L, at 45 sites), and vinyl chloride (1.08 ppmv = 2.8 ug/L, at 46 sites).

The authors cited above also note that the concentrations of VOCs in NMOC gas are variable over time and, over the very long term, VOC generation will become a very small part of the landfill gas. The implication is that the volatile nature of the COCs is such that they tend to find migration routes out of the waste pile, most probably via diffusion. The degradation of certain synthetic material, particularly since there is a fixed mass of waste at the point of facility closure, the VOC fraction of the waste will eventually decline.

Hoffman and Chiarappa (1998) and Hoffman and others (1999) conducted studies of VOC migration relative to the tortuosity of various unconsolidated sediments, which impact diffusion rates through soil. Those studies yielded a range of a retardation factors that reduced diffusion time through soils by 0.2 to 0.8. Tortuosity is not directly considered in the POLLUTE model.

An additional factor of sorption plays into the diffusion process, with clay particles and organic content acting to remove some organic constituents from water and gas. The POLLUTE model can apply a distribution coefficient to accommodate that aspect of the diffusion process.

Scheutz (2002) notes that methanotrophic bacteria in landfill soil covers are able to co-oxidize large quantities of VOCs, in some cases to the point of non-detection. Oxidation processes will dechlorinate the dichloroethene isomers and vinyl chloride, but reducing environments are more effective in the dechlorination of larger halogenated carbon compounds.

Since the effective diffusion value differs for various VOCs, and since the physical characteristics of the soil affect the diffusivity of the gas, the POLLUTE model attempts to develop a flux by using the effective porosity and bulk density of the model soil.

The POLLUTE model does not account for any chemical processes that might occur in either vapor or solute phase in the linear calculations. That is, the dechlorination of PCE to VC cannot be accommodated unless the non-linear sorption or passive sink options are engaged.

General Background and Assumptions

Both the site-specific model and the prescribed design model consist of a geomembrane (GM) underlain by a clay soil layer. Both assume there is an aquifer with an overlying aquitard.

Source

The source concentrations of VOCs in landfill leachate and landfill gas are an important point of discussion. The POLLUTE model allows several options based primarily on VOC concentration and landfill size. The model can be run using either a constant source concentration or a finite mass of VOC in the waste. If the finite mass is used, additional input data or assumptions are required from the user.

Concentration

The Billings Regional Landfill conducted a Tier II NMOC evaluation in 2007. The objective of the evaluation is to determine if the facility will reach a threshold of non-methane gas generation that would trigger the installation of a gas-capture system that would eliminate fugitive emissions. The evaluation consisted of sampling 51 locations within the waste, analyzing the gas samples, correcting the nitrogen and oxygen contents of the samples, determining the non-methane concentration of the gas, and applying the resultant data to the LandGEM model as a means of estimating future production of NMOC gases. The Billings landfill has a design capacity that exceeds the number of years allowed in the LandGEM model. The model, by default, allows the evaluation to continue for 80 years, two years short of the anticipated lifespan of the Billings facility. Predictions, therefore, are only available up to the year 2048. We feel that, for the purposes of this investigation, that is a sufficiently long model period.

The LandGEM model includes an option to predict specific VOCs. That option is based on EPA estimates of VOC concentrations in landfill gas derived from their own studies and literature-based data. In the case of the Billings facility, LandGEM predicts the vinyl chloride production at the facility in 2048 to be 1.036 tons (0.9422 megagrams; Mg) or 326 cubic meters (m3: Appendix B).

The POLLUTE model requires an input in terms of mass per unit volume. For the year 2048 the LandGEM model predicts a total of 4.965 x 107 m3 and a vinyl chloride mass of 1.036 Mg. The concentration of vinyl chloride, then is 9.433×10^{11} micrograms (ug) divided by 4.965×10^{10} liters (L), or 19 ug/L.

Landfill Length

This parameter involves the length of the landfill parallel to the direction of flow of the leachate collection system, which, in this case, is 950 feet.

Source Type

Two different inputs are allowed: a constant concentration, or; a finite mass. The constant concentration option assumes that the concentration of the COC remains constant over the span of the model run. The finite mass option requires inputs for waste thickness, which, according the facility master plan, is 125 feet.

Infiltration

The POLLUTE model also requires a moisture-infiltration rate. In this instance, that figure is not readily calculated for a number of reasons. For example, one section of the landfill (Phase 2) is closed with an evapotranspiration cover, so should receive little, if any, infiltration. Conversely, Phase 4 is receiving both recirculated leachate as a surface application and gas-extraction condensate via a horizontal well. The gas extraction process has provided over 120,000 gallons of moisture to Phase 3, and approximately 25,000 gallons of leachate from the pond has been sprayed on Phase 3. That cell is approximately 9 acres, so the additional moisture amounts to only 0.59 inches. The annual average precipitation is 14.3 inches, so assuming that moisture will be recirculated on and/or within Phase 5, the use of 15 inches of infiltration is conservative. The model unit requirements require recalculation of that value to 0.0034 feet per day (1.25 feet/365.25 days).

Waste Density

The other required inputs to the model are waste density, which is assumed at 1,200 pounds per cubic yard (about 711 kilograms per cubic meter.

Percent of Mass

The POLLUTE model requires a mass of leachable contaminant per unit mass of the waste. The percentage of leachable COC, in this case, vinyl chloride, of a given mass of waste could be quite variable. The LandGEM model predicts the generation of 57 Mg vinyl chloride over the entire lifespan plus 60 years post-closure at the Billings Regional landfill. If the predicted 1.6-percent increase in the waste acceptance rate reasonable, the total mass waste in 2048 (80 years after opening) would be just over 17,000,000 Mg. The predicted vinyl chloride production in the last year of the model amounts to 0.09 Mg, in contrast to the peak production of 0.9 Mg in 2049. The production curve (Figure 4) generated by the model implies that vinyl chloride would be produced at a declining rate for some time after the year 2109. Using the total mass and vinyl chloride production within the LandGEM model limits, the mass of leachable gas would be 0.00034 percent. To be conservative, and to account for the long-term production, we use a percent of mass of 0.001 percent in the model.

Hydraulic Heads

Two inputs are required by the model.

Leachate Head on Primary Liner

The leachate head is assumed to be the one-foot (30 cm) maximum allowed by ARM 17.50.1200.

Groundwater Level Relative to Top of Aquifer

The groundwater at the Billings facility does not appear to maintain any artesian head. The groundwater level relative to the top of the aquifer is assumed to be zero.

Geomembranes

The geomembrane input considers thickness, diffusion coefficient, and the method of calculating leakage.

Thickness

The proposed alternative liner is designed to have a 60-mil (1.523 mm) HDPE membrane as the upper part of the barrier system.

Diffusion Coefficient

The POLLUTE model input requires a diffusivity value for geomembrane, clay liner and attenuation layer. A review of available literature (Rowe and others, 1995; Rowe ,1997; Rowe and Brachman, 2004, and; Lake and Rowe, 2005) reveals that diffusivity coefficients for either synthetic or naturally-occurring materials are not commonly developed, probably due to the hazardous nature of the compound. However, methylene chloride has been used by researches to develop coefficients for those materials. While methylene chloride and vinyl chloride exhibit a number of physical differences, we feel that the similarities in molecular weight, density and diffusivity make for a reasonable substitution. The diffusivity inputs for this model, therefore, are based on literature values for methylene chloride and assigned as 2.0×10^{-8} cm^2/sec.

Leakage Method

The software author's default methodology is the preferred process.

Leakage

The Leakage inputs control leachate migration through the barrier system. The geomembrane is considered to be impervious to water when intact.

Hole Frequency

The default hole frequency is one hole per acre (2.5 holes per hectare).

Hole Radius

The default hole radius of 0.00564 m (0.22 inches; area of 0.152 inches), which is the default for the program.

Wrinkle Radius

Rowe (2005) has determined, through laboratory aging of a number of liner materials and field-based data, that wrinkles in geomembranes can constitute a significant source of leakage over time. The Wrinkle Radius used for the model is the default value of 0.155 inches

CFLAG

The CFLAG value is either 1 or 0 depending upon the boundary. CFLAG is 1 when head in the underlying aquifer is greater than zero, and is 0 when the head is greater than the thickness of the soil layer above the first aquifer. In this case, the aquifer head is greater than zero but less than the attenuation layer thickness.

Transmissivity (THETA)

The transmissivity referred to in this instance pertains to the contact between the GM and the CCL. The value used for this model is 1.0×10^{-10} m^2/sec, which is the suggested default value for a liner that has good overall contact with the soil. The model offers values for "perfect" contact, which is probably unrealistic in most instances.

Conductivity

In this case, the conductivity refers to the hydraulic conductivity of the material directly overlying the GM. This is used in the model to determine flow through holes and wrinkles. Since uncompacted native material will be used, we assigned the lowest of the values reported for the Phase 2 closure construction materials, 2.5×10^{-4} cm/sec, as the conductivity of the protective layer.

Clay Liner

The inputs for the CCL are similar to those for the Geomembrane, but require some additional definitions.

Thickness

The thickness for the prescribed composite liner model is two feet. The actual proposed thickness for the recompacted soil layer of the alternative liner is one foot or zero for areas where the native soil meets the moisture-density, compaction and hydraulic conductivity specifications. The hydraulic conductivity of the shale underlying Phase 5 ranges from 2.19×10^{-11} to 4.64×10^{-7} cm/sec, and the geometric mean of all of the samples (both recompacted and cores) is 1.73×10^{-9} cm/sec. We assume that some disturbance of the soil will occur over the entire site, which could reduce that average hydraulic conductivity by as much as an order of magnitude. Therefore, we assume that there will be a zone of at least 0.5 feet that will have a hydraulic conductivity of 1×10^{-7} cm/sec.

Density

A number of tests have been conducted on the substrate within the Phase 5 unit. The calculated bulk dry density of a sample taken at a depth of 15 feet from test boring DH-1 was 102.9 pounds per cubic foot (pcf) or 1.65 grams per cubic centimeter (gm/cm^3).

Conductivity

The hydraulic conductivity of the CCL in both model scenarios has been assigned 1×10^{-7} cm/sec, which is the regulatory minimum.

Diffusion Coefficient

As with the geomembrane model inputs, a diffusion coefficient specific to the CCL for a specific COC is required. In this case, Lake and Rowe (2004) conducted tests on a limited number of VOCs, and present a value of 6 x 10^{-10} m^2/sec (6 x 10^{-6} cm^2/sec) for DCM through a CCL.

Distribution Coefficient

The distribution coefficient is a measure of the potential attenuation of a VOC in a particular soil, primarily based on the COC's affinity to adsorption onto organic or soil particles. The carbon content has not been measured at the site, but is assumed to be normal for a marine shale. Soil adsorption coefficients (K_{oc}) for VC are variously reported as 14 to 131. However, since the adsorption potential cannot be verified from on-site samples, the distribution coefficient is assigned as zero.

Porosity

The porosity of nine samples taken within and proximal to the Phase 5 cell averages to 0.254 (Table 3). That average includes a recompacted sample from a depth of 15 to 20 feet below the existing surface that yielded a porosity of 0.41. Samples taken from deeper in that same boring had porosities of 0.258 to 0.279. Samples of the shale taken from greater depths, including three cores from DH-2, had much lower porosities, in the range of 0.14 to 0.19. We feel that the average value of 0.254 is reasonable because it represents a mean that is slightly lower than what was found beneath the proposed waste unit. That is a conservative value because the smaller void volume increases the diffusion of gases in the model. The model does not account for tortuosity.

Attenuation Layer (Aquitard)

As with the geomembrane and the CCL, the aquitard requires a delineation of physical attributes. The model considers the aquitard to represent an attenuation layer capable of transmitting and removing a certain percentage of pollutants.

Thickness

The thickness of the attenuation layer is described above. The assumed thickness of the attenuation layer is 180 feet.

Density

Table 3 shows the attributes of the substrate beneath and proximal to the proposed waste unit. The bulk dry density of the material underlying Phase 5 is calculated to be 1.65 g/cm^3, or 102.9 pcf.

Conductivity

The geometric mean of hydraulic conductivities returned from the analysis of soils underlying and proximal to the proposed Phase 5 unit is 1.73 x 10^{-9} cm/sec. The geometric mean of the hydraulic conductivity values reported for samples from test boring DH-1, directly underlying the proposed cell, is 2.697 x 10^{-8} cm/sec. That mean value includes three samples, two of which were in the 10^{-9} cm/sec range. The hydraulic conductivity of three core samples taken from test boring DH-3, located just outside of the proposed cell on its southern boundary, ranged in the 10^{-11} cm/sec range. Given this of information, we feel that the use of the geometric mean value of 2.7 x 10^{-8} cm/sec from test boring DH-1 is reasonable and conservative.

Diffusion Coefficient

As with the other layers of the model, a diffusion coefficient for the attenuation layer is required for the attenuation layer. Values reported by Carpenter and others (1993), Lake and Rowe (2004), Rowe (2005) and Rimal and Rowe (2009) indicate that the diffusion coefficient of naturally-occurring clay and mechanically-mixed fine-grained soils for the COC ranges from 2 to 6 x 10^{-6} cm^2/sec (2-6 x 10^{-10} m^2/sec). Based on that, along with the diffusion coefficient reported by Lake and Rowe (2004) for compacted clay liners, a value of 6 x 10^{-6} cm^2/sec is used for the model.

Distribution Coefficient

Based on the same arguments presented for the CCL, above, the distribution coefficient for the attenuation layer is assigned as zero.

Porosity

Based on previous work (Table 1) as described for the Clay Layer, above, a porosity of 0.25 is assigned to the attenuation layer.

Aquifer

The lowermost layer of the model represents the aquifer.

Thickness

The thickness of water-bearing units is problematic. Drilling logs indicate that such units range from a foot to a few feet in thickness, and are not within easily-delineated or discrete geological units. A thinner water-bearing zone would be more likely to concentrate contaminants that diffused or flowed through overlying strata. Therefore, we have assigned a one-foot thickness to the modeled aquifer thickness.

Porosity

The porosity of any water-bearing zones is unknown. For the purposes of the model, we have assigned the porosity as 0.3, which is slightly higher than that of the attenuation layer, in spite of the fact that the water-bearing zones comprise the same geological material.

Run Parameters

The run parameters control the type and timing of the model outputs. The model is set up to produce concentrations at specific times. Currently, the Billings Regional Landfill is not slated to close until 2050, so we set the model up to run for the lifetime of the Phase 5 unit (2012-2050) plus 60 years.

Model Results

Appendix B contains the results of the models described above, as well as additional outputs for maximum concentrations and sensitivity analyses. Please note that the output text lists the landfill length as 289.56 meters. The landfill length is 980 feet, but an apparent bug in the software lists the length in meters. Note also that the POLLUTE software interprets the length and height of the waste mass for the fixed mass option as one unit wide, thereby producing an output that accounts for time and concentration with depth.

Prescribed Liner

Given the inputs described above, a model gas having the general behavior of methylene chloride using a concentration of vinyl chloride predicted by NMOC testing would fall below the detection limit used by the DEQ for volatile organic compounds in soils (+/- 10^{-3} ug/L) at a depth of less than 25 feet below the base after 98 years.

Proposed Alternative Liner

Using the inputs described above, but replacing the clay sub-base with six inches of disturbed soil, the model predicted that the COC concentrations after 98 years would fall below the DEQ detection limit at a depth of less than 20 feet.

Maximum Potential Concentrations

Both baseline models predicted that the maximum concentration of the liner and attenuation layer would be attained after 9,900 years. The model predicted that the maximum concentration at 187 feet would be 0.01 ug/L of the COC.

Sensitivity Analysis

Sensitivity analyses can be conducted in any number of ways. The POLLUTE model offers a range of sensitivity analysis options including the initial source concentrations, Darcy velocity, layer thickness, diffusion coefficient and distribution coefficient. Previous experience with the POLLUTE model, along with the knowledge that the Belle Fourche formation underlying the Phase 5 unit is relatively homogeneous, allowed the investigators to eliminate hydraulic conductivity (Darcy velocity), layer thickness, and porosity from consideration for a sensitivity analysis. In the case of the Phase 5 waste cell, the shale is relatively uniform in its properties, with the exception that some pores, fractures and bedding planes within the strata are filled with bentonite. That condition would affect the diffusion coefficient, at least to some degree. A run of the model with a diffusion coefficient two orders of magnitude greater than the initial model shows a potential for deeper infiltration of gas. The 100-year run predicted concentrations of the COC at a depth of 185 feet below the waste unit to be an order of magnitude above the DEQ detection limit for gas sampling. Another run using a diffusion coefficient one order of magnitude greater than the initial runs predicted that, after 100 years, the COC would be undetectable 80 feet below the base of the cell.

Interpretation of Results

Predicted Values

The POLLUTE model predicted that the model COC could attain detectable concentrations at depths of 20 to 25 feet. While it may seem counter-intuitive, the proposed liner system appeared to perform better than the prescribed liner system. The reason for that is the difference in physical characteristics between a two-foot clay liner and the native shale. The shale is, in reality, less permeable and less porous than a recompacted clay liner. For the purposes of this investigation, the model shows that the existing ground is at least as protective of groundwater as a two-foot recompacted clay layer.

Attenuation

The longer-term, maximum concentration runs predicted deeper penetrations of landfill gas over time. That, however, is not necessarily a realistic scenario. Any number of aspects of the POLLUTE model for the Billings facility can be points of contention. We have constructed the model on what we consider to be an extremely conservative basis using the best data available. The model does not account for any attenuation, which is conservative but unrealistic. As anaerobic conditions develop in the waste mass, some percentage of the parent compounds of VC, such as PCE and TCE will be dechlorinated. The resulting DCE isomers and VC can be attenuated by methanotrophic bacteria living in the oxygenated soil surrounding the cover and portions of the liner (Scheutz, 2002). Other VOCs can be attenuated by complexing with organic and inorganic compounds that develop in the leachate, which will presumably be removed via the leachate collection system for at least the life of the facility. Assuming the final cover is either vented or consists of an evapotranspiration cover, considerable masses of VOCs will simply escape to the atmosphere. A fraction of the landfill gas can also escape through the leachate collection system. A small fraction of some VOCs will simply be contained for a period as they adsorb onto the carbonaceous material within the waste mass. The model does not account for preferential pathways, which would allow landfill gas to migrate laterally through strata that have higher porosity or lower tortuosity, and which are better-connected to atmospheric venting conditions. Given all of the potential for attenuation, a model that assumes none can be considered conservative.

Another potential attenuation factor not integrated into the model involves the adsorption potential of the Belle Fourche shale. Gautier (1985) and Ho and Meyers (1987) report organic carbon contents ranging from 0.2 to 4.3 percent organic carbon in the formation in Phillips County, Montana and Johnson County, Wyoming. VOCs will adsorb onto organic carbon, and there no reason to believe that such a process will not occur in the substrate beneath the proposed Phase 5 waste-fill area.

Also note that the width and depth dimensions used in the model represent 125 feet of waste over the entire 950 feet of cell length. Those dimensions cannot be applied over the entire waste unit because the sides are sloped, so when the input dimensions are applied to the entire cell, the waste mass is over-estimated by as much as 20 percent.

Mitigating Conditions

An important mitigating factor pertaining to landfill gas involves the gas-to-energy system at the Billings facility. The system is currently in place and will be expanded into Phase 5 as it is being filled. Records obtained from Montana-Dakota Utilities indicates that as much as 490 metric tons of methane are being recovered annually from the extraction system. That fact is very important in considering the modeling effort as well as *in-situ* conditions.

We feel it highly unlikely that only 490 metric tons of methane is being captured if the total methane production is on the order of 21,000 tons as predicted by the LandGEM model. Those values imply that the collection network is collecting only 2.3 percent of the methane being produced. The system currently in place at the Billings facility only covers over half of the the entire mass of waste, but it is still reasonably efficient. Using the GHG-calculated values for methane generation, the recovery rate for 2011 would be over 12 percent, which is a more reasonable rate of capture. At that, the existing waste pile was not producing enough methane for capture, and additional intake lines had to be installed. We find it unlikely that the methane generation is as high as predicted by the LandGEM model and, therefore, the concentration of VOCs and NMOCs is probably not as high as implied in the model.

The fact that a large percentage of the landfill gas is being removed means that there is a lower mass of VOCs and NMOCs in the landfill gas. While the percentage of those constituents may remain the same, the presumption of the mass-based gas production used in the POLLUTE model also represents an over-estimation.

The mechanical removal of the landfill gas has certain physical effects on gas migration. As the gas is removed from the waste pile, a number of phenomena occur. The internal pressure of the gas is at least reduced, if not entirely eliminated. That is, if gas extraction rates exceed gas production (which appears to be the case in at least part of the collection system), the voids must be filled with another gas, presumably of atmospheric origin. That implies that some portions of the waste mass will experience a dilution effect of the landfill gas. At the very least, the internal gas pressure of the capped waste mass will be reduced, thereby reducing the effect of one of the mechanisms that can lead to gas leakage through the liner system.

Conclusion and Summary

The subsurface underlying the proposed waste cell comprises carbonaceous shale of the Cretaceous-aged Belle Fourche formation, and consists of at least 94 percent fines (passing #200 sieve) and, in places, contains as much as 55 percent clay. Measured hydraulic conductivities range from the 10^{-11} to the 10^{-7} cm/sec range, with the geometric mean of values produced from samples underlying and proximal to the proposed cell being 1.73×10^{-9} cm/sec. The average porosity is calculated to be 0.254 and the bulk dry density is assumed to be 102.9 pcf, the latter being based on a single analysis from the cell base.

The liner design consists of, from top to bottom, 16 inches of gravel cover, a 16-ounce non-woven fabric, 60 mil HDPE liner with two-sided texture, and native soil. Native soil that does not meet the compaction requirements will be excavated to a depth of six inches and replaced with appropriately-compacted soil.

Using data from the physical properties of the soil, along with literature-based diffusion estimates, the POLLUTE model predicts that the proposed liner design for the Phase 5 waste unit at the Billings Regional Landfill is at least as protective of the environment as the prescriptive cover design developed by the Montana DEQ. The model inputs included gas production rates and content based on the LandGEM model and data collected from the facility for a 2007 NMOC Tier II gas evaluation. The model may be considered conservative because no additional attenuation factors were introduced and there is a good probability that the LandGEM estimates for gas production are an order of magnitude high. The model predicted the model COC to be at undetectable levels less than 25 feet below the Phase 5 cell 98 years after the cell closure. That time period includes the entire lifespan of the facility plus 60 years of post-closure time. A 10,000-year model run predicts COC concentrations at a depth of 185 feet to be about 1×10^{-2} ug/L, one order of magnitude higher than the DEQ-established detection limit for gas sampling at hazardous waste facilities of 0.001 ug/L.

Additional mitigating factors include the relatively high organic carbon component of the Belle Fourche shale and the landfill gas-to-energy system that will actively remove methane and the VOCs associated with landfill gas from the proposed Phase 5 unit.

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Appendix A

Geotechnical Investigation, Billings Landfill Phase V Expansion

TETRA TECH

Report of

Geotechnical Investigation
Billings Landfill Phase V Expansion

Billings, Montana

April 2012

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Report of Geotechnical Investigation

Billings Landfill Phase V Expansion
Billings, Montana

Prepared for:

Great West Engineering

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Tetra Tech Project No. 114-550852

4-2-12

April 2, 2012

TETRA TECH

April 2, 2012

Mr. Bruce Siegmund
Great West Engineering
PO Box 4817
Helena, Montana 59604

SUBJECT: Geotechnical Investigation
Billings Landfill Phase V Expansion
Billings, Montana
Tetra Tech Project No. 114-550852

Dear Mr. Siegmund:

At your request, we have performed a limited geotechnical investigation at the site of the proposed Billings Landfill Phase V Expansion located in Billings, Montana. The report that follows describes in detail our investigation, summarizes our findings, and presents our opinions regarding the similarity of engineering properties of the soil and bedrock between the Phase V expansion and the expansions previously explored.

It is important that we provide consultation during design, and field services during construction, to review and monitor implementation of the geotechnical recommendations.

If you have any questions regarding this report, please contact us. We appreciate the opportunity to provide geotechnical engineering services to you on this project.

Respectfully submitted,

Tetra Tech

Travis Goracke, P.E.
Geotechnical Engineer

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(in four copies)

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EXECUTIVE SUMMARY

The project consists of the expansion of a section of the Billings Landfill to determine if subsurface soil and bedrock conditions are favorable for the construction of an additional cell for disposal of waste. The proposed cell location is directly southwest of the scale house and is approximately 24 acres in size.

On February 20 and 21, 2012, three exploration borings were drilled to identify subsurface soil, bedrock, and groundwater conditions. The subsurface profile in boring DH-1 generally consisted of six feet of lean clay fill overlying shale bedrock, which extends beyond the maximum depth explored, 50.4 feet. The subsurface profile in boring DH-2 generally consisted of shale bedrock extending from the ground surface to beyond the maximum depth explored, 40.5 feet. The subsurface profile in boring DH-3 generally consisted of 15 feet of lean clay fill underlain by shale bedrock which extends beyond the maximum depth explored, 90 feet. Groundwater was not encountered in the borings at the time of the field exploration. Numerous factors contribute to groundwater fluctuations, and evaluation of such factors is beyond the scope of this report.

As requested, the geotechnical investigation was performed to determine if the subsurface soil and bedrock encountered below the proposed Phase V cell expansion has similar engineering properties and the lithology was generally similar to that identified for the exploration borings previously performed for the Phase III and IV expansions. Our findings and conclusions can be found later in this report.

We have prepared this executive summary solely to provide a general overview. This executive summary should not be relied on for any purpose except for that for which it was prepared. Only the full report should be relied on for information about findings, recommendations and other concerns.

PURPOSE AND SCOPE OF STUDY

The purpose of this study is to determine the subsurface lithology of the proposed Phase V cell area and determine if it is consistent with previous expansions explored at the landfill. We understand that if the subsurface soil and bedrock have similar engineering properties, and are encountered at similar depths, the field exploration will provide sufficient design information to provide approval of an alternative liner for Phase V. As requested, historical data from previous investigations, including laboratory testing, has been reviewed and is included in this report.

Tetra Tech, Inc. conducted a field exploration program consisting of drilling three exploration borings in the area of the proposed Phase V expansion to obtain information on site and subsurface conditions. Samples obtained during the field investigation were tested in Tetra Tech's laboratory to determine the physical and engineering characteristics of the on-site soils and bedrock. Results of the field investigation and laboratory tests were analyzed to characterize the site material properties. This report summarizes the field data and presents conclusions based on the proposed construction and subsurface conditions encountered. The investigation was performed in accordance with Tetra Tech's contract with Great West Engineering dated February 9, 2012.

This study does not address a slope stability analysis or provide liner recommendations for the Phase V expansion.

PROJECT DESCRIPTION

The proposed project consists of the expansion of the Billings Landfill within its current property limits to add an additional cell for disposal of waste. The cell is located directly southwest of the existing scale house. The proposed new cell is approximately 24 acres in size and is located between an existing access road to the south, the scale house on the north, existing cells to the east and an existing communications tower to the west. Excavation depth to the base of the cell will vary based on the construction of a new leachate collection system. The project site and proposed cell location are shown on Drawing No. 550852-1.

Looking northeast toward Boring DH-3.

FIELD EXPLORATION

The field exploration was conducted on February 20 and 21, 2012. Three borings were drilled at the locations shown on Drawing No. 550852-1 to explore subsurface soil, bedrock, and groundwater conditions. Borings were advanced through the overburden soils and bedrock with a truck-mounted drill rig equipped with 8-¼-inch diameter hollow-stem augers. The borings were logged by a Tetra Tech representative.

Samples of the upper subsurface materials were taken with 2-inch outside-diameter split-spoon samplers driven into the various strata using a 140-pound hammer falling 30 inches. The number of blows required to advance the sampler each successive 6-inch increment was recorded; the total number of blows required to advance the sampler the second and third 6-inch increments is the penetration resistance (N value). This is the standard penetration test described by American Society for Testing and Materials (ASTM) Method D1586. Penetration resistance values indicate the relative density or consistency of the soils. Bulk samples and split spoon samples of soil were obtained from the hollow-stem augers at locations chosen by the field engineer. Sample depths were recorded on the field log and are shown on the logs of exploration borings.

LABORATORY TESTING

Samples obtained during the field exploration were taken to Tetra Tech's laboratory, where they were observed and visually classified in accordance with ASTM D2487, which is based on the Unified Soil Classification System. Representative samples were selected for testing to determine the engineering and physical properties of the soils in general accordance with ASTM or other approved procedures.

Tests Conducted:	To Determine:
Grain-size Distribution	Size and distribution of soil particles (i.e., clay, silt, sand, and gravel).
Natural Moisture Content	Moisture content representative of field conditions at the time samples were taken.
Atterberg Limits	The effect of varying water content on the consistency of fine-grained soils.
Moisture-Density Relationship	The optimum moisture content for compacting soil and the maximum dry unit weight (density) for a given compactive effort.
Hydraulic Conductivity	The rate with which water will flow through soil.

Field and laboratory test results are summarized on Figures 4 through 22 in the Appendix. These data and the field information were used to prepare the exploration boring logs on Figures 1 through 3.

LOCAL GEOLOGY

The landfill is located in the western half of Section 29 and the eastern half of Section 30, Township 1S, Range 26E and is about 4.5 miles southwest of Billings, Montana. This area marks the southern valley wall to the ancestral floodplain for the Yellowstone River. Maximum relief between the ridge tops and floodplain ranges from about 250 feet to 330 feet. Many of the north-facing slopes along the valley wall are oversteepened as a result of erosion at the toe by past meandering of the Yellowstone River. Topography above the floodplain is dissected by secondary, intermittent drainages forming parallel trending ridgelines and steep V shaped drainages profiles. Inclination of side slopes in secondary drainages range from approximately 33 to 35 degrees near the crestline steepening to between 42 to 57 degrees on the sidewalls.

Hills in the area are comprised of redeposited alluvial clay soils overlying claystone-shale from the Mowery formation. The shale is lower Cretaceous in age. When viewed in cross-section, the slope inclination increases at the transition from clay soil to claystone-shale. This contact is readily identifiable within the landfill site.

At most exposed claystone-shale outcrop locations, clay soil is encountered at the top of the bedrock. Upon inspection of the clay soil texture, thin parallel platelets of shale and claystone are observed. This information indicates an old erosional surface existed at the top of the claystone-shale which was subsequently buried by more recent clay soil deposits. The old bedrock topography can be characterized as moderate rolling hills and U shaped drainages.

The Cretaceous claystone-shale is encountered extensively throughout the landfill. It is typically dark gray in color, fissile, thinly laminated and jointed. When exposed, the shale slakes and weathers near the surface but becomes hard and competent with increasing depth of penetration. Occasional highly plastic beds varying from about one foot to several feet thick are interbedded throughout the shale.

SUBSURFACE CONDITIONS

The subsurface profile in boring DH-1 generally consisted of six feet of lean clay fill overlying shale bedrock, which extends beyond the maximum depth explored, 50.4 feet. The subsurface profile in boring DH-2 generally consisted of shale bedrock extending from the ground surface to beyond the maximum depth explored, 40.5 feet. The subsurface profile in boring DH-3 generally consisted of 15 feet of lean clay fill underlain by shale bedrock which extends beyond the maximum depth explored, 90 feet. Groundwater was not encountered in the borings at the time of the field exploration.

The boring logs should be referenced for complete descriptions of the soil and rock types and their estimated depths. A characterization of the subsurface profile normally includes grouping soils with similar physical and engineering properties into a number of distinct layers. The representative subsurface layers at the site are presented below, starting at the ground surface.

FILL

Fill was encountered at the surface in Boring DH-3. The fill visually classifies as lean clay according to ASTM D2487. The fill contained scattered fine grained sand lenses and fine to coarse subrounded gravel. Penetration resistance values ranged from 14 to 16 blows per foot. The natural moisture content varies from 10 to 29 percent.

Lean CLAY (CL)

Lean clay was encountered at the surface in Boring DH-1. The clay visually classifies as lean clay according to ASTM D2487. Penetration values in the clay are on the order of 10 blows per foot which is indicative of a stiff soil stratum. The natural moisture content ranged from 15 to 19 percent.

SHALE

Shale was encountered below the clay in Boring DH-1, at the surface in Boring DH-2, and below the fill in Boring DH-3. The shale is medium hard to hard with medium to high plasticity characteristics. Penetration values in the shale bedrock exceeded 50 blows per foot. Specific gravities performed on the shale bedrock ranged from 2.66 to 2.73. The natural moisture content varies from 7 to 17 percent. Liquid and plastic limit tests indicate the shale has a liquid limit varying from 42 to 67 percent and a plasticity index varying from 23 to 46 percent (Figures 4 through 12). A moisture density relationship test performed on the shale indicates a maximum dry density on the order of 102.9 pounds per cubic foot at optimum moisture content of 19.6 percent (Figure 13). A hydraulic conductivity test performed on a sample of shale bedrock remolded to 95 percent of the maximum dry density, as determined by ASTM D698, indicates a rate of 4.64×10^{-7} centimeters per second (Figure 14). Hydraulic conductivity tests performed on samples of shale bedrock remolded to near in-place density measured indicate a rate varying from 2.56×10^{-9} to 7.87×10^{-9} centimeters per second (Figures 15 through 19). Hydraulic conductivity tests performed on undisturbed core samples of shale bedrock indicate a rate varying from 2.19×10^{-11} to 7.16×10^{-11} centimeters per second (Figures 20 through 22).

GROUNDWATER

Groundwater was not encountered in the borings at the time of the field exploration. Numerous factors contribute to groundwater fluctuations, and evaluation of such factors is beyond the scope of this report.

CONCLUSIONS

The requested scope of work for this project was to determine if the subsurface lithology of the proposed Phase V expansion area was generally similar to that encountered in the exploration borings performed for the Phase III and IV expansions located to the north. The requested scope was also to determine if the subsurface soil and bedrock have similar engineering properties, and are encountered at similar depths as the previous expansions.

When comparing our findings from the field investigation performed for this study to the previous investigations performed in February of 2009 and in March and April of 2007, minor variations in the subsurface profile such as the thickness of the fill, clay and claystone were observed. This can be attributed to an irregular bedrock contact variations in the existing topography and disturbance from previous landfill operations and excavations. The hydraulic conductivity rates from samples obtained in the Phase III expansion ranged from 1.9×10^{-9} to 3.8×10^{-9} centimeters per second. Samples from the Phase IV expansion ranged from 1.09×10^{-8} to 3.36×10^{-9} centimeters per second. In general, it is our opinion that the subsurface profile and engineering properties of the bedrock and soil stratum encountered at the Phase V expansion are similar to those encountered in the Phase III and IV expansions.

It should be noted that slope stability and liner recommendations were not requested or addressed by this study. Due to the limited number of borings drilled at the site, it is possible that soil and rock conditions may differ from those included in this report. Tetra Tech should observe the excavation prior to the placement of the plastic liner to verify soil and bedrock conditions are similar to those encountered during the field exploration. If needed, further investigation and additional recommendations can be provided at your request.

CONTINUING SERVICES

Two additional elements of geotechnical engineering service are important to the successful completion of this project.

1. **Consultation with Tetra Tech, Inc. during the design phase.** This is essential to ensure that the intent of our recommendations is incorporated in design decisions related to the project and that changes in the design concept consider geotechnical aspects.

2. **Observation and monitoring during construction.** Tetra Tech should be retained to observe the earthwork phases of the project, to determine that the subsurface conditions are compatible with those used in our analysis and design. Placement of fill should be observed on a full time basis and tested to confirm that the required density has been achieved. In addition, if environmental contaminants or other concerns are discovered in the subsurface, Tetra Tech professionals are available for consultation.

LIMITATIONS

This study has been conducted in accordance with generally accepted geotechnical engineering practices in the region where the work was conducted. The conclusions and recommendations submitted in this report are based upon project information provided to Tetra Tech and data obtained from the exploratory borings drilled at the locations indicated. The nature and extent of subsurface variations across the site may not become evident until construction. Tetra Tech should be on site during construction, to verify that actual subsurface conditions are consistent with those described herein.

This report has been prepared exclusively for our client. This report and the data included herein shall not be used by any third party without the express written consent of both the client and Tetra Tech. Tetra Tech is not responsible for technical interpretations by others. As the project evolves, we should provide continued consultation and field services during construction to review and monitor the implementation of our recommendations, and verify that our recommendations have been appropriately interpreted. Significant design changes may require additional analysis or modifications of the recommendations presented herein. We recommend on-site observation of excavations and foundation bearing strata and testing of fill by a representative of the geotechnical engineer.

Prepared by: Travis Goracke, P.E. Reviewed by: Jared Jung, P.E.

Appendices

IMPORTANT INFORMATION
ABOUT YOUR
GEOTECHNICAL ENGINEERING REPORT

More construction problems are caused by site subsurface conditions than any other factor. As troublesome as subsurface problems can be, their frequency and extent have been lessened considerably in recent years, due in large measure to programs and publications of ASFE/The Association of Engineering Firms Practicing in the Geosciences.

The following suggestions and observations are offered to help you reduce the Geotechnical-related delays, cost-overruns and other costly headaches that can occur during a construction project.

A GEOTECHNICAL ENGINEERING REPORT IS BASED ON A UNIQUE SET OF PROJECT-SPECIFIC FACTORS

A Geotechnical engineering report is based on a subsurface exploration plan designed to incorporate a unique set of project-specific factors. These typically include: the general nature of the structure involved, its size and configuration; the location of the structure on the site and its orientation; physical concomitants such as access roads, parking lots, and underground utilities, and the level of additional risk which the client assumed by virtue of limitations imposed upon the exploratory program. To help avoid costly problems, consult the geotechnical engineer to determine how any factors which change subsequent to the date of the report may affect its recommendations.

Unless your consulting Geotechnical engineer indicates otherwise, *your Geotechnical engineer report should not be used:*

- When the nature of the proposed structure is changed, for example, if an office building will be erected instead of a parking garage, or if a refrigerated warehouse will be built instead of an unrefrigerated one;
- when the size or configuration of the proposed structure is altered;
- when the location or orientation of the proposed structure is modified:
- when there is a change of ownership, or
- for application to an adjacent site.

Geotechnical engineers cannot accept responsibility for problems which may develop if they are not consulted after factors considered in their reports' development have changed.

MOST GEOTECHNICAL "FINDINGS" ARE PROFESSIONAL ESTIMATES

Site exploration identifies actual subsurface conditions only at those points where samples are taken, when they are taken. Data derived through sampling and subsequent laboratory testing are extrapolated by geotechnical engineers who then render an opinion about overall subsurface conditions, their likely reaction to proposed conditions, their likely reaction to proposed construction activity, and appropriate foundation design. Even under optimal circumstances actual conditions may differ from those inferred to exist, because no Geotechnical engineer, no matter how qualified, and no subsurface exploration program, no matter how comprehensive, can reveal what is hidden by earth, rock and time. The actual interface between materials may be far more gradual or abrupt than a report indicates. Actual conditions in areas not sampled may differ from predictions. *Nothing can be done to prevent the unanticipated, but steps can be taken to help minimize their impact.* For this reason, *most experienced owners retain their Geotechnical consultants through the construction stage,* to identify variances, conduct additional tests which may be needed, and to recommend solutions to problems encountered on site.

SUBSURFACE CONDITIONS CAN CHANGE

Subsurface conditions may be modified by constantly-changing natural forces. Because a Geotechnical engineering report is based on conditions which existed at the time of subsurface exploration, *construction decisions should not be based on a Geotechnical engineering report whose adequacy may have been affected by time.* Speak with the Geotechnical consultant to learn if additional tests are advisable before construction starts.

Construction operations at or adjacent to the site and natural events such as flood, earthquakes or groundwater fluctuations may also affect subsurface conditions and, thus, the continuing adequacy of a geotechnical report. The geotechnical engineer should be kept apprised of any such events, and should be consulted to determine if additional tests are necessary.

GEOTECHNICAL SERVICES ARE PREFORMED FOR SPECIFIC PURPOSES AND PERSONS

Geotechnical engineers' reports are prepared to meet the specific needs of specific individuals. A report prepared for a consulting civil engineer may not be adequate for a construction contractor, or even some other consulting civil engineer. Unless indicated otherwise, this report was prepared expressly for the client involved and expressly for purposes indicated by the client. Use by any other persons for any purpose, or by the client for a different purpose, may result in problems. *No individual other than the client should apply this report for its intended purpose without first conferring with the geotechnical engineer. No person should apply this report for any purpose other than that originally contemplated without first conferring with the geotechnical engineer.*

A GEOTECHNICAL ENGINEERING REPORT IS SUBJECT TO MISINTERPRETATION

Costly problems can occur when other design professionals develop their plants based on misinterpretations of a geotechnical engineering report. To help avoid these problems, the geotechnical engineer should be retained to work with other appropriate design professionals to explain relevant geotechnical findings and to review the adequacy of their plans and specifications relative to geotechnical issues.

BORING LOGS SHOULD NOT BE SEPARATED FROM THE ENGINEERING REPORT

Final boring logs are developed by geotechnical engineers based upon their interpretation of field logs (assembled by site personnel) and laboratory evaluation of field samples. Only final boring logs customarily are included in geotechnical engineering reports. *These logs should not under any circumstances be redrawn* for inclusion in architectural or other design drawings, because drafters may commit errors or omissions in the transfer process. Although photographic reproduction eliminates this problem, it does nothing to minimize the possibility of contractors misinterpreting the logs during bid preparation. When this occurs, delays, disputes and unanticipated costs are the all-too-frequent result.

To minimize the likelihood of boring log misinterpretation, *give contractors ready access to the complete geotechnical engineering report* prepared or authorized for their use. Those who do not provide such access may proceed under the *mistaken* impression that simply disclaiming responsibility for the accuracy of subsurface information always insulates them from attendant liability. Providing the best available information to contractors helps prevent costly construction problems and the adversarial attitudes which aggravate them to disproportionate scale.

READ RESPONSIBILITY CLAUSES CLOSELY

Because geotechnical engineering is based extensively on judgment and opinion, it is far less exact than other design disciplines. This situation has resulted in wholly unwarranted claims being lodged against geotechnical consultants. To help prevent this problem, geotechnical engineers have developed model clauses for use in written transmittals. These are *not* exculpatory clauses designed to foist geotechnical engineers' liabilities onto someone else. Rather, they are definitive clauses which identify where geotechnical engineers' responsibilities begin and end. Their use helps all parties involved recognize their individual responsibilities and take appropriate action. Some of these definitive clauses are likely to appear in your geotechnical engineering report, and you are encouraged to read them closely. Your geotechnical engineer will be pleased to give full and frank answers to your questions.

OTHER STEPS YOU CAN TAKE TO REDUCE RISK

Your consulting geotechnical engineer will be pleased to discuss other techniques which can be employed to mitigate risk. In addition, ASFE as developed a variety of materials which may be beneficial. Contact ASFE for a complimentary copy of its publications directory.

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THE ASSOCIATION OF ENGINEERING FIRMS PRACTICING IN THE GEOESCIENCES

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TETRA TECH

LOGS OF EXPLORATIONS
EXPLANATION OF ABBREVIATIONS AND DESCRIPTIVE TERMS

SSS (SPT)	-	Standard penetration resistance test – results recorded as the number of blows of a 140-pound hammer falling 30 inches required to drive a 2-inch O.D. split sample spoon the second and third 6-inch increments of an 18-inch distance.
LSS	-	Modified penetration test – results recorded as the number of blows of a 140-pound hammer falling 30 inches required to drive a 2.5-inch O.D. split spoon the second and third 6-inch increments of an 18-inch distance.
SRS	-	Split barrel ring sampler 2-inches I.D. for taking undisturbed samples.
LRS	-	Split barrel ring sampler 2.5 inches I.D. for taking undisturbed samples.
STS	-	Shelby tube sampler for taking undisturbed samples (2" to 3-5/16" I.D.).
Sack (SK) or Bag	-	Sample of disturbed soil placed in canvas sack or plastic bag.
GWL	-	Groundwater level on the date shown on the logs.
RQD	-	Rock quality designation (RQD) for the bedrock samples are determined for each core run by summing the length of all sound, hard pieces of core over four inches in length, and dividing this number by the total length of the core run. This value, along with the core recovery percentage, is recorded on the drill logs.

GRAIN SIZES

	U.S. Standard Series Sieve				Clear Square Sieve Openings	
	200	40	10	4 ¾"	3"	12"
Silts & Clays Distinguished on Basis of Plasticity	SAND			GRAVEL		Cobbles Boulders
	Fine	Medium	Coarse	Fine	Coarse	

CONSISTENCY		RELATIVE DENSITY	
Clays & Silts	SPT* Blows/foot	Sands & Gravels	SPT* Blows/foot
Very Soft	0 – 2	Very Loose	0 – 4
Soft	3 – 4	Loose	5 – 10
Firm	5 – 8	Medium Dense	11 – 30
Stiff	9 – 15	Dense	31 – 50
Very Stiff	15 – 30	Very dense	Over 50
Hard	Over 30		

*Standard Penetration Test; PL = Plastic Limit; LL = Liquid Limit

CLASSIFICATION OF SOILS FOR ENGINEERING PURPOSES

TETRA TECH

ASTM Designation: D 2487 - 83

(Based on Unified Soil Classification System)

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests[A]				Soil Classification: Group Symbol	Soil Classification: Name[B]
Coarse-Grained Soils More than 50% retained on No. 200 sieve	Gravels More than 50% coarse fraction retained on No. 4 sieve	Clean Gravels Less than 5% fines[C]	$Cu \geq 4$ and $1 \leq Cc \leq 3$[E]	GW	Well graded gravel[F]
			$Cu < 4$ and/or $1 > Cc > 3$[E]	GP	Poorly graded gravel[F]
		Gravels with Fines More than 12% fines[C]	Fines classify as ML or MH	GM	Silty gravel[F,G,H]
			Fines classify as CL or CH	GC	Clayey gravel[F,G,H]
	Sands 50% or more of coarse fraction passes No. 4 sieve	Clean Sands Less than 5% fines[D]	$Cu \geq 6$ and $1 \leq Cc \leq 3$[E]	SW	Well-graded sand[I]
			$Cu < 6$ and/or $1 > Cc > 3$[E]	SP	Poorly graded sand[I]
		Sands with Fines More than 12% fines[D]	Fines classify as ML or MH	SM	Silty sand[G,H,I]
			Fines classify as CL or CH	SC	Clayey sand[G,H,I]
Fine-Grained Soils 50% or more passes the No. 200 sieve	Silts and Clays Liquid limit less than 50	inorganic	PI>7 and plots on or above "A" line[J]	CL	Lean clay[K,L,M]
			PI<4 or plots below "A" line[J]	ML	Silt[K,L,M]
		organic	$\frac{\text{Liquid limit - oven dried}}{\text{Liquid limit - not dried}} < 0.75$	OL	Organic clay[K,L,M,N] Organic silt[K,L,M,O]
	Silts and Clays Liquid limit 50 or more	inorganic	PI plots on or above "A" line	CH	Fat clay[K,L,M]
			PI plots below "A" line	MH	Elastic silt[K,L,M]
		organic	$\frac{\text{Liquid limit - oven dried}}{\text{Liquid limit - not dried}} < 0.75$	OH	Organic clay[K,L,M,P]
					Organic silt[K,L,M,Q]
Highly organic soils	Primarily organic matter, dark in color, and organic odor			PT	Peat

[A] Based on the material passing the 3-in. (75-mm) sieve.

[B] If field sample contained cobbles or boulders, or both, add "with cobbles or boulders, or both" to group name.

[C] Gravels with 5 to 12% fines require dual symbols:
- GW-GM well-graded gravel with silt
- GW-GC well-graded gravel with clay
- GP-GM poorly graded gravel with silt
- GP-GC poorly graded gravel with clay

[D] Sands with 5 to 12% fines require dual symbols:
- SW-SM well-graded sand with silt
- SW-SC well-graded sand with clay
- SP-SM poorly graded sand with silt
- SP-SC poorly graded sand with clay

[E] $Cu = D_{60}/D_{10}$ $Cc = \frac{(D_{30})^2}{D_{10} \times D_{60}}$

[F] If soil contains ≥15% sand, add "with sand" to group name.

[G] If fines classify as CL-ML, use dual symbol GC-GM, or SC-SM.

[H] If fines are organic, add "with organic fines" to group name.

[I] If soil contains ≥15% gravel, add "with gravel" to group name.

[J] If Atterberg limits plot in hatched area, soil is a CL-ML, silty clay.

[K] If soil contains 15 to 29% plus No. 200, add "with sand" or "with gravel", whichever is predominant.

[L] If soil contains ≥30% plus No. 200, predominantly sand, add "sandy" to group name.

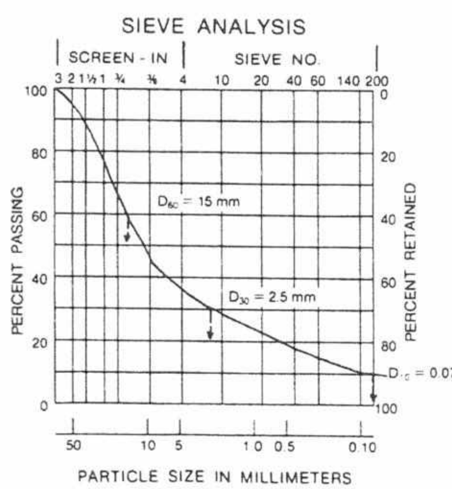
[M] If soil contains ≥30% plus No. 200, predominantly gravel, add "gravelly" to group name.

[N] PI≥4 and plots on or above "A" line.

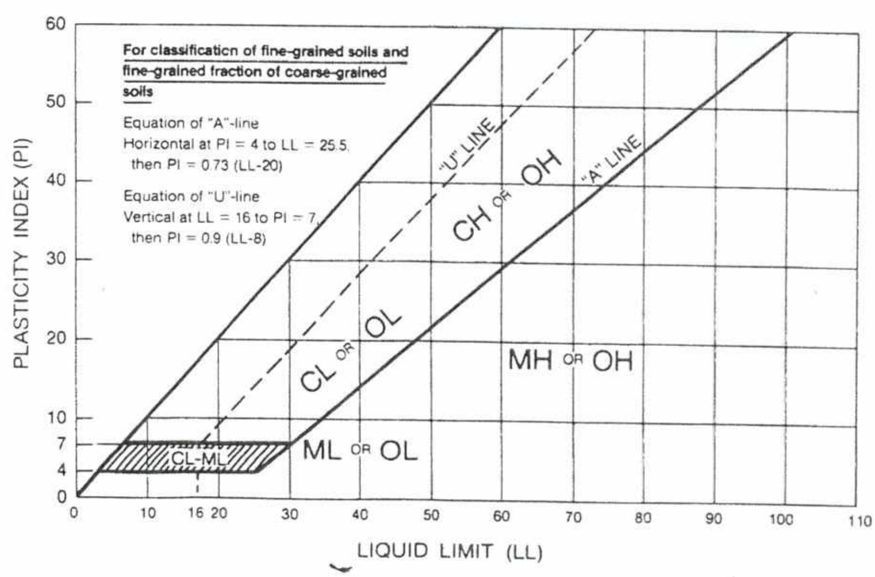
[O] PI<4 or plots below "A" line.

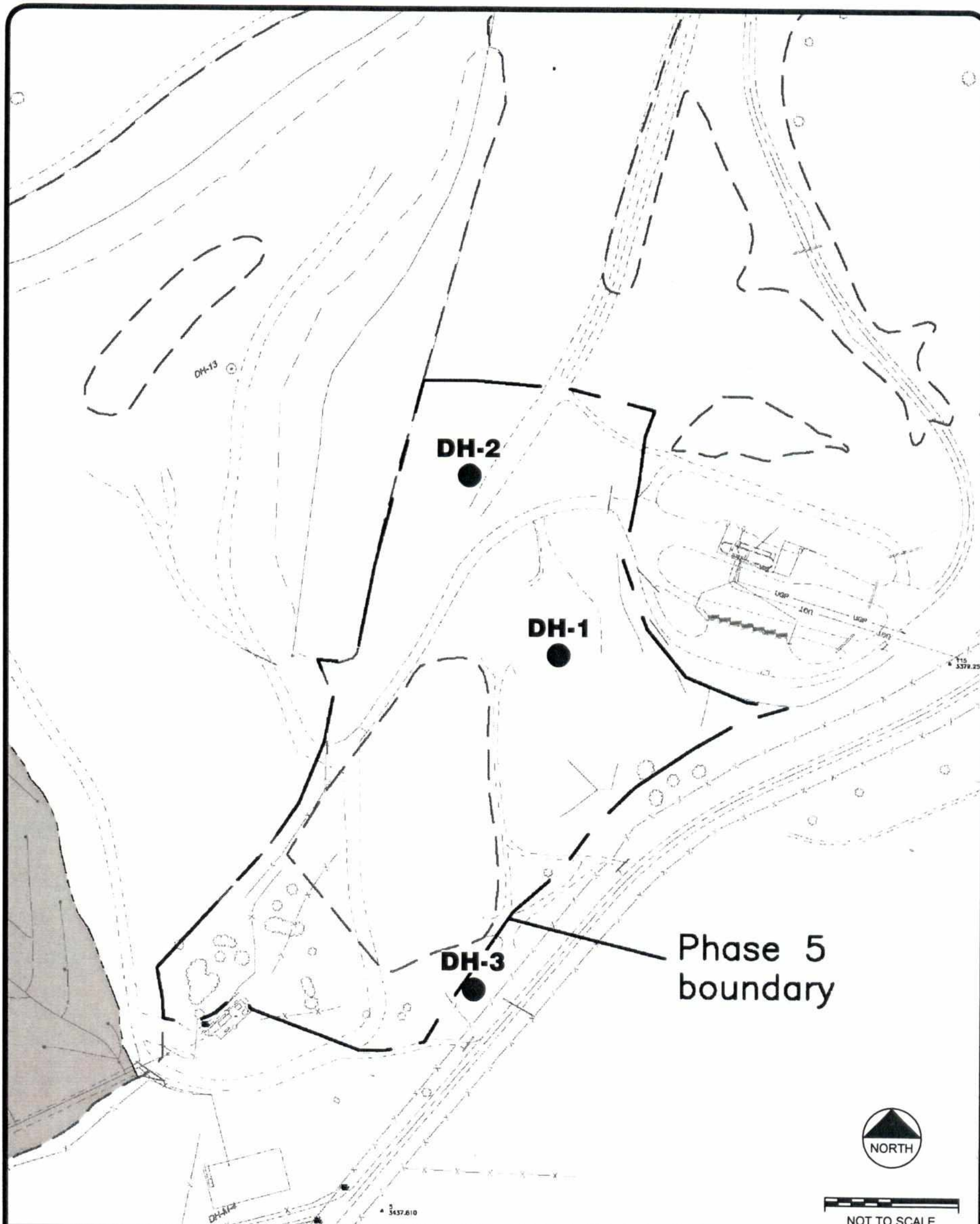
[P] PI plots on or above "A" line.

[Q] PI plots below "A" line.



$C_U = \frac{D_{60}}{D_{10}} = \frac{15}{0.075} = 200$ $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}} = \frac{(2.5)^2}{0.075 \times 15} = 5.6$





TETRA TECH www.tetratech.com	Client: Great West Engineering	Project No.: 114-550852
	Billings Landfill Phase V Expansion Billings, Montana	Date: March 2012
		Drawn By: MAT
618 South 25th Street Billings, MT 59101-4549 PHONE: 406-248-9161 FAX: 406-248-9282	LOCATION OF EXPLORATORY BORINGS	DRAWING 550852-1

Project Name:	Billings Landfill Phase V Expansion
Borehole Location:	See Drawing 550852-1
Sheet	1 of 1
Borehole Number:	DH-1
Driller:	Haztech
Logger:	Travis Goracke
Drilling Equipment:	BK-81
Borehole Diameter (in.):	8.25
Date Started:	2-20-12
Date Finished:	2-20-12
Elevation and Datum:	Ground: 3383
Notes:	Center Boring. Elevation provided by Great West Engineering.

DEPTH (ft)	STANDARD PENETRATION TEST SPT	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	LIQUID LIMIT LL	PLASTICITY INDEX PI	-200 (%)	MATERIAL DESCRIPTION	DEPTH (ft)
	2-2-8	19.5					**Lean CLAY** - brown, moist.	
		15.0						
							SHALE - gray, moderately hard rock, moist, weathered in the upper 2 feet, blocky structure in the upper 8 feet, thinly laminated from 8.5 to 50.4 feet.	6
	15-22-26							
10	15-29-41	13.7						
	36-50/0.4	9.1	118.3	43	24	97		
20	44-50/0.2	8.3						
	42-50/0.2	9.0	136.1	44	26	98		
30	47-50/0.2	8.6						
	50/0.5	10.1	121	59	40	99		
40	44-50/0.2	9.9						
	50/0.4	10.6	123.1	67	46	93		
50	50/0.4						End of Boring.	50.4

Sampler Types: Split Spoon; Penetrometer; Shelby; Vane Shear; Bulk Sample; California; Grab Sample; Test Pit

Operation Types: Auger; Hand Auger; Air Rotary; Core Barrel; Excavated Pit

WATER LEVEL OBSERVATIONS

While Drilling: Dry ft   Upon Completion of Drilling: Dry ft

Time After Drilling

Depth To Water (ft)

Remarks:

Project Name: Billings Landfill Phase V Expansion			
Borehole Location: See Drawing 550852-1			Sheet 1 of 1
Borehole Number: DH-2		Driller: Haztech	Logger: Travis Goracke
Drilling Equipment: BK-81	Borehole Diameter (in.): 8.25	Date Started: 2-20-12	Date Finished: 2-20-12
Elevation and Datum: Ground: 3350	Notes: North Boring. Elevation provided by Great West Engineering.		

DEPTH (ft)	DRILL OPERATION	SAMPLE	STANDARD PENETRATION TEST SPT	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	LIQUID LIMIT LL	PLASTICITY INDEX PI	-200 (%)	GRAPHIC LOG	MATERIAL DESCRIPTION	DEPTH (ft)
			4-13-24	15.2						**SHALE** - gray, moderately hard rock, moist, upper 2 feet is weathered, blocky structure in the upper 5 feet, thinly laminated from 5 to 40.5, bentonite noted in 40 foot splitspoon.	
			18-33-50/0.3	12.7							
10			34-50/0.4	8.5							
			50/0.5	6.7							
20			50/0.4	7.9	122.6	43	24	97			
			50/0.4	7.8							
30			50/0.4	8.5							
			50/0.4	7.3	126.1	45	27	93			
40			50/0.5	17.4							40.5

End of Boring.

Sampler Types: Split Spoon; Shelby; Bulk Sample; Grab Sample; Penetrometer; Vane Shear; California; Test Pit

Operation Types: Hand Auger; Auger; Air Rotary; Core Barrel; Excavated Pit

WATER LEVEL OBSERVATIONS

While Drilling Dry ft Upon Completion of Drilling Dry ft

Time After Drilling

Depth To Water (ft)

Remarks:

114-550852	TETRA TECH	**LOG OF EXPLORATORY BORING DH-2**	Fig. 2

Project Name: Billings Landfill Phase V Expansion					
Borehole Location: See Drawing 550852-1				Sheet 1 of 2	
Borehole Number: DH-3			Driller: Haztech	Logger: Travis Goracke	
Drilling Equipment: BK-81		Borehole Diameter (in.): 8.25	Date Started: 2-21-12	Date Finished: 2-21-12	
Elevation and Datum: Ground: 3458		Notes: South Boring. Elevation provided by Great West Engineering.			

DEPTH (ft)	DRILL OPERATION	SAMPLE	STANDARD PENETRATION TEST SPT	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	LIQUID LIMIT LL	PLASTICITY INDEX PI	-200 (%)	GRAPHIC LOG	MATERIAL DESCRIPTION	DEPTH (ft)
	Auger	Bulk Sample	8-8-7	10.5						**FILL - Lean Clay** - brown, stiff to very stiff, moist, scattered fine grained sand lenses and fine to coarse subrounded gravel.	
	Auger	Split Spoon	5-6-10	28.8							
10	Auger	Split Spoon	4-5-9	16.8							
	Auger	Bulk Sample	5-9-11	39.1						**BENTONITE** - yellow to gray, very soft rock, moist, blocky structure, high plasticity.	15
20	Auger	Split Spoon	13-24-26	13.8						**SHALE** - gray, moderately hard rock, weathered from 18 to 33 feet, blocky structure from 18 to 33 feet, thinly laminated from 33 to 76.8	18
	Auger	Split Spoon	14-16-17	12.9							
30	Auger	Split Spoon	11-17-21	13.0							
	Core Barrel									Highly fractured zone noted from 35 to 37 feet.	
	Core Barrel									Iron staining noted in joint at 36.8 feet. Broken zone with thin bentonite lenses noted from 37 to 37.2 feet, maintained circulation.	
40	Core Barrel									Iron staining noted in joint at 41.5 feet.	
50	Core Barrel										

Sampler Types: Split Spoon; Shelby; Bulk Sample; Grab Sample; Penetrometer; Vane Shear; California; Test Pit

Operation Types: Hand Auger; Auger; Air Rotary; Core Barrel; Excavated Pit

WATER LEVEL OBSERVATIONS

While Drilling ▽ Dry ft   Upon Completion of Drilling ▼ Dry ft

Time After Drilling

Depth To Water (ft)

Remarks:

114-550852	TETRA TECH	**LOG OF EXPLORATORY BORING DH-3**	Fig. 3

Project Name: Billings Landfill Phase V Expansion	
Borehole Location: See Drawing 550852-1	Sheet 2 of 2
Borehole Number: DH-3	Driller: Haztech / Logger: Travis Goracke
Drilling Equipment: BK-81 / Borehole Diameter (in.): 8.25	Date Started: 2-21-12 / Date Finished: 2-21-12
Elevation and Datum: Ground: 3458	Notes: South Boring. Elevation provided by Great West Engineering.

DEPTH (ft)	MOISTURE CONTENT (%)	DRY DENSITY (pcf)	LIQUID LIMIT LL	PLASTICITY INDEX PI	-200 (%)	MATERIAL DESCRIPTION	DEPTH (ft)
	6.5	146.3	42	23	95	**SHALE** - gray, moderately hard rock, weathered from 18 to 33 feet, blocky structure from 18 to 33 feet, thinly laminated from 33 to 76.8	
60							
						6 inch weathered zone noted at 65 feet, highly fractured from 65 to 68 feet, maintained circulation.	
						Bentonite infilling noted in joints at 68 feet.	
70	7.3	138.7	48	28	98	6-inch weathered zone noted at 69.5 feet.	
						BENTONITE - yellow to gray, very soft rock, blocky structure, high plasticity.	76.8
						SHALE - gray, moderately hard rock, thinly laminated.	77.7
80							
						Bentonite infilling noted in joint at 81.8 feet.	
	7.6	137.5	55	32	99		
						Thin interbedded bentonite seams noted from 88.2 to 88.6 feet.	
90						6-inch bentonite zone noted from 89.5 to 90 feet.	90
						End of Boring.	

Sampler Types: Split Spoon, Shelby, Bulk Sample, Grab Sample, Penetrometer, Vane Shear, California, Test Pit

Operation Types: Hand Auger, Auger, Air Rotary, Core Barrel, Excavated Pit

WATER LEVEL OBSERVATIONS

While Drilling Dry ft   Upon Completion of Drilling Dry ft

Time After Drilling

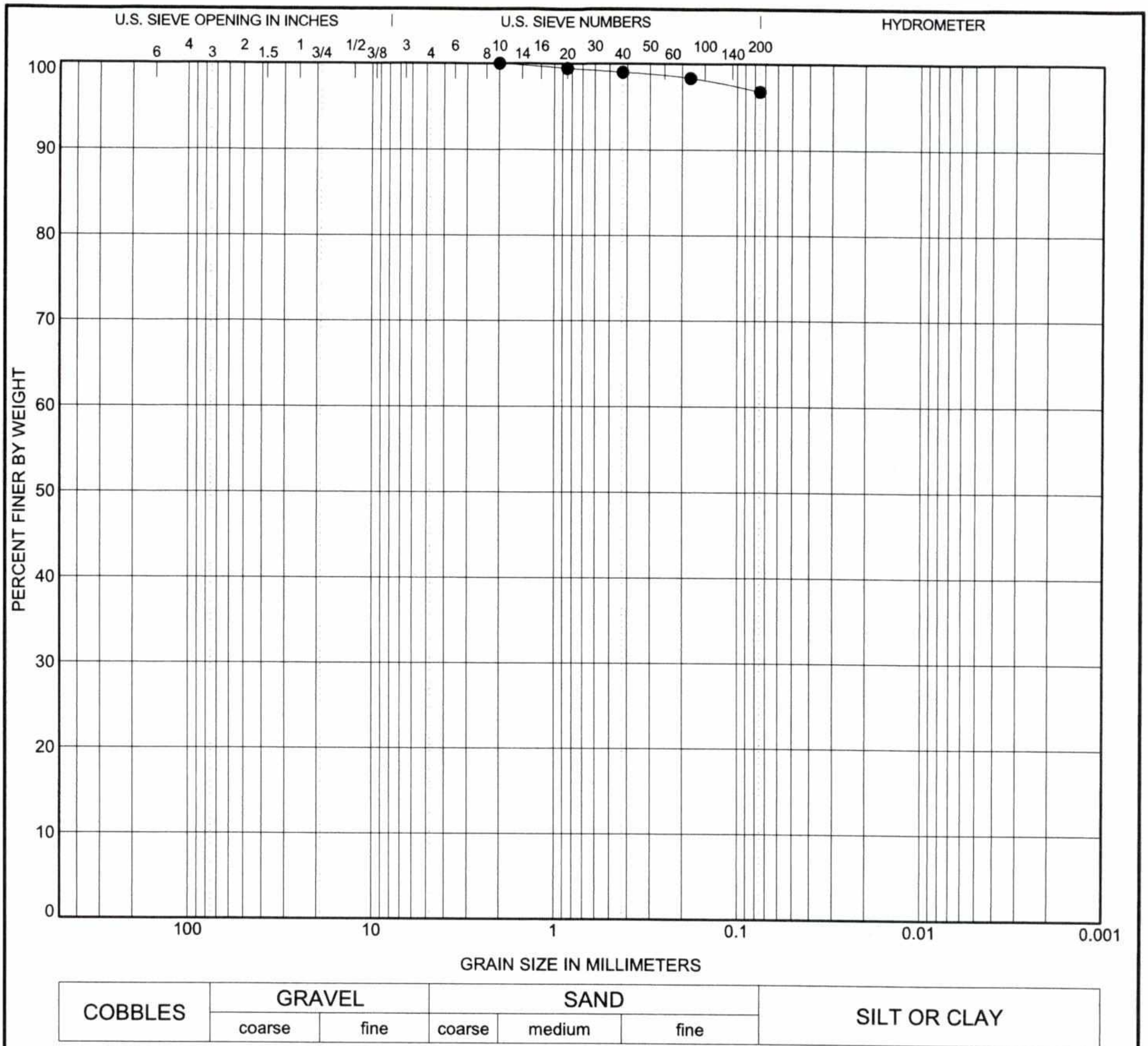
Depth To Water (ft)

Remarks:

114-550852	TETRA TECH	LOG OF EXPLORATORY BORING DH-3	Fig. 3

Revised 1-01-07 (MAT)

BILLINGS LANDFILL LOGS.GPJ 3-27-12 CASPER ENGLISH (BOR) W/SH & SAME FIG TT library 1-10 (MAT)



Specimen Identification	Classification	LL	PL	PI	Cc	Cu
DH-1 - (15 - 15.9 ft)	**LEAN CLAY(CL)**	**43**	**19**	**24**		

Specimen Identification	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
DH-1 - (15 - 15.9 ft)	**2**				**0**	**3**	**97**	

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Billings Landfill Phase V Expansion

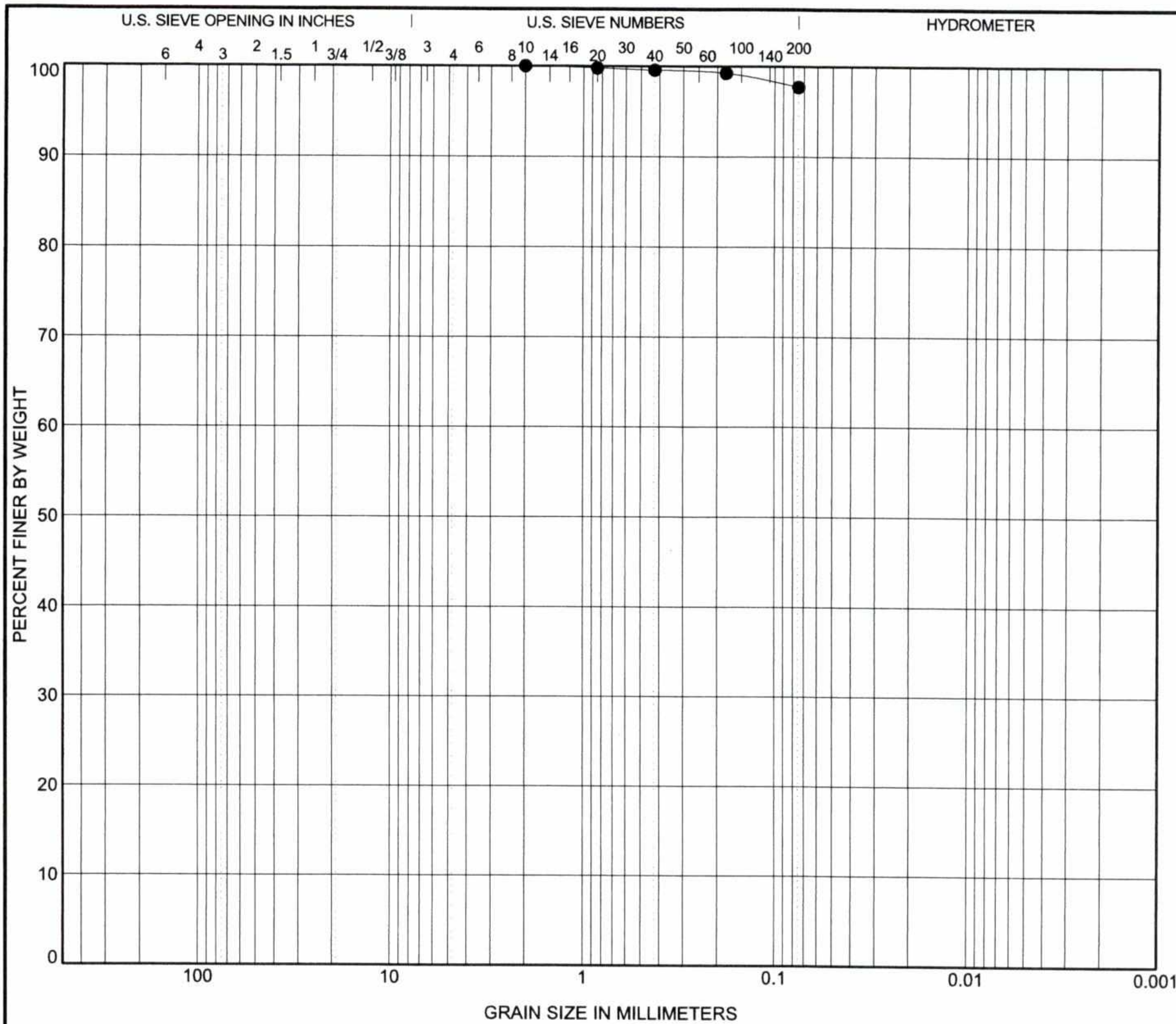
Location: See Drawing 550852-1

Number: 114-550852

Figure No. 4

BILLINGS LANDFILL LOGS.GPJ 3-29-12 TT_US GRAIN SIZE

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Specimen Identification	Classification	LL	PL	PI	Cc	Cu
DH-1 - (25 - 25.7 ft)	**LEAN CLAY(CL)**	**44**	**18**	**26**		

Specimen Identification	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
DH-1 - (25 - 25.7 ft)	**2**				**0**	**2**	**98**	

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Billings Landfill Phase V Expansion

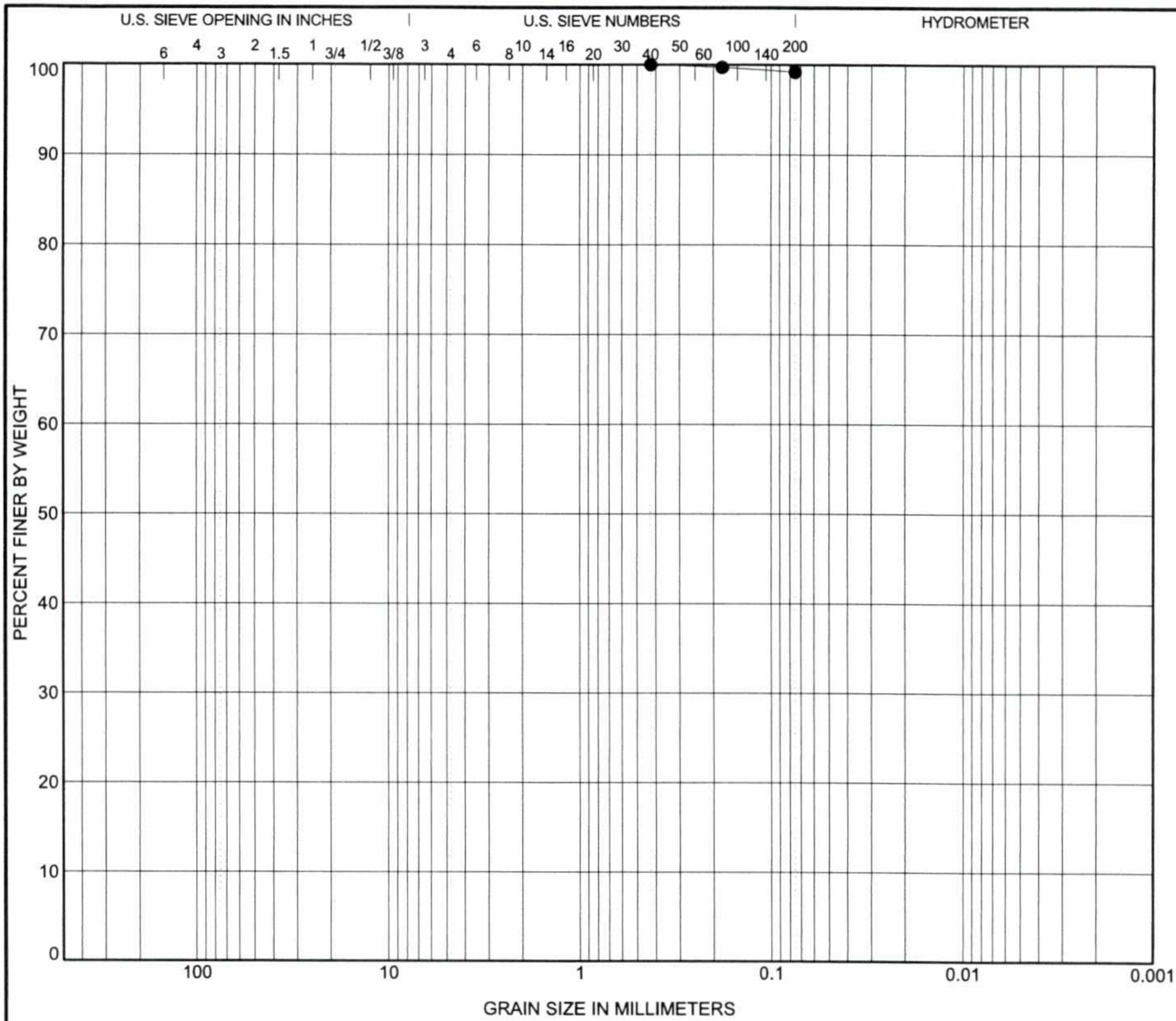
Location: See Drawing 550852-1

Number: 114-550852

Figure No. 5

BILLINGS LANDFILL LOGS.GPJ 3-29-12 TT_US GRAIN SIZE

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Specimen Identification	Classification	LL	PL	PI	Cc	Cu
DH-1 - (35 - 35.5 ft)	**FAT CLAY(CH)**	**59**	**19**	**40**		

Specimen Identification	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
DH-1 - (35 - 35.5 ft)	**0.425**				**0**	**1**	**99**	

BILLINGS LANDFILL LOGS.GPJ ' 3-29-12 ' ' TT_US GRAIN SIZE

TETRA TECH

GRAIN SIZE DISTRIBUTION

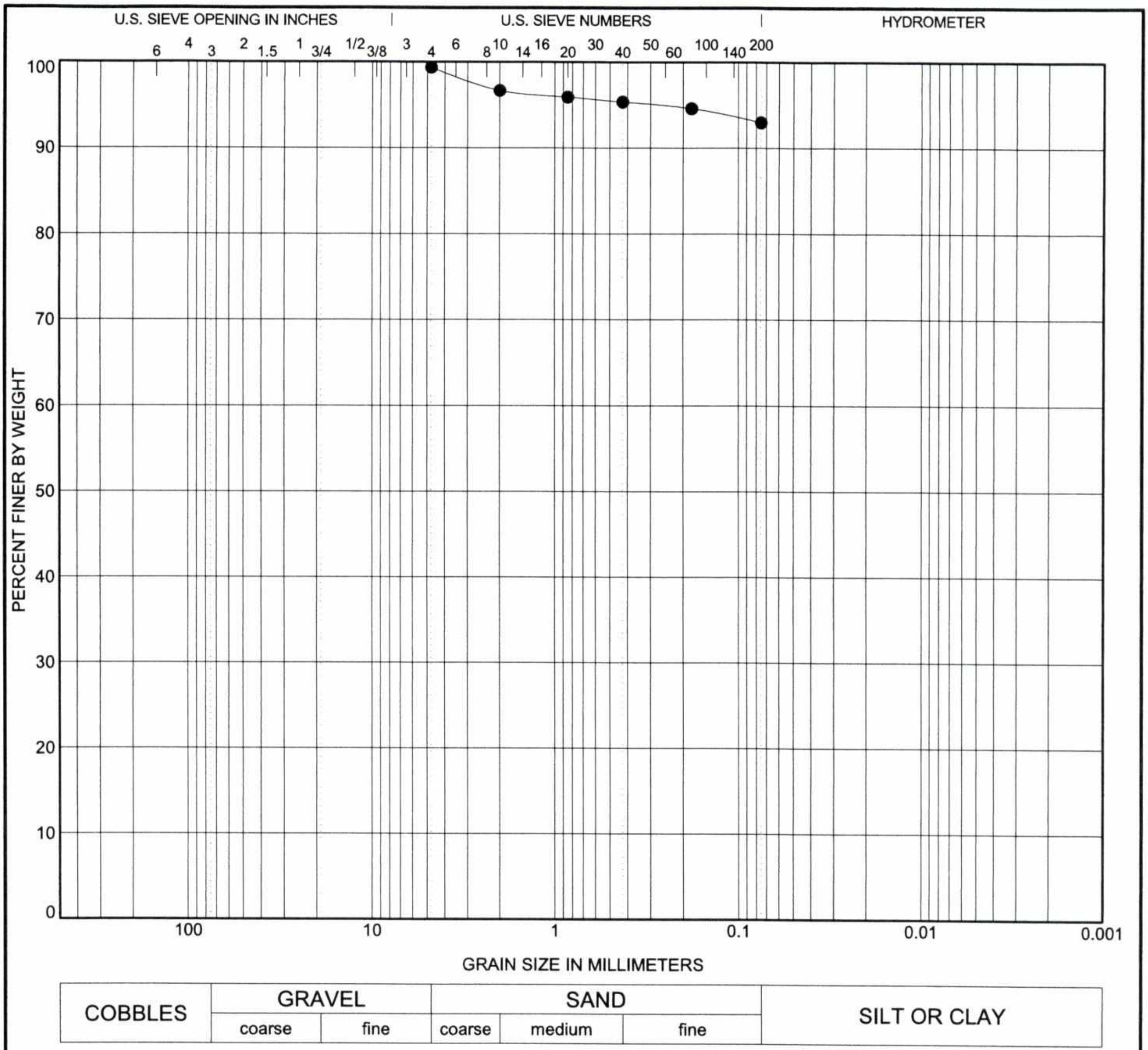
Project: Billings Landfill Phase V Expansion

Location: See Drawing 550852-1

Number: 114-550852

Figure No. 6

Revised 1-23-08 (MAT)



Specimen Identification	Classification	LL	PL	PI	Cc	Cu
DH-1 - (45 - 45.4 ft)	**FAT CLAY(CH)**	**67**	**20**	**47**		

Specimen Identification	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
DH-1 - (45 - 45.4 ft)	**4.75**				**0**	**6**	**93**	

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Billings Landfill Phase V Expansion

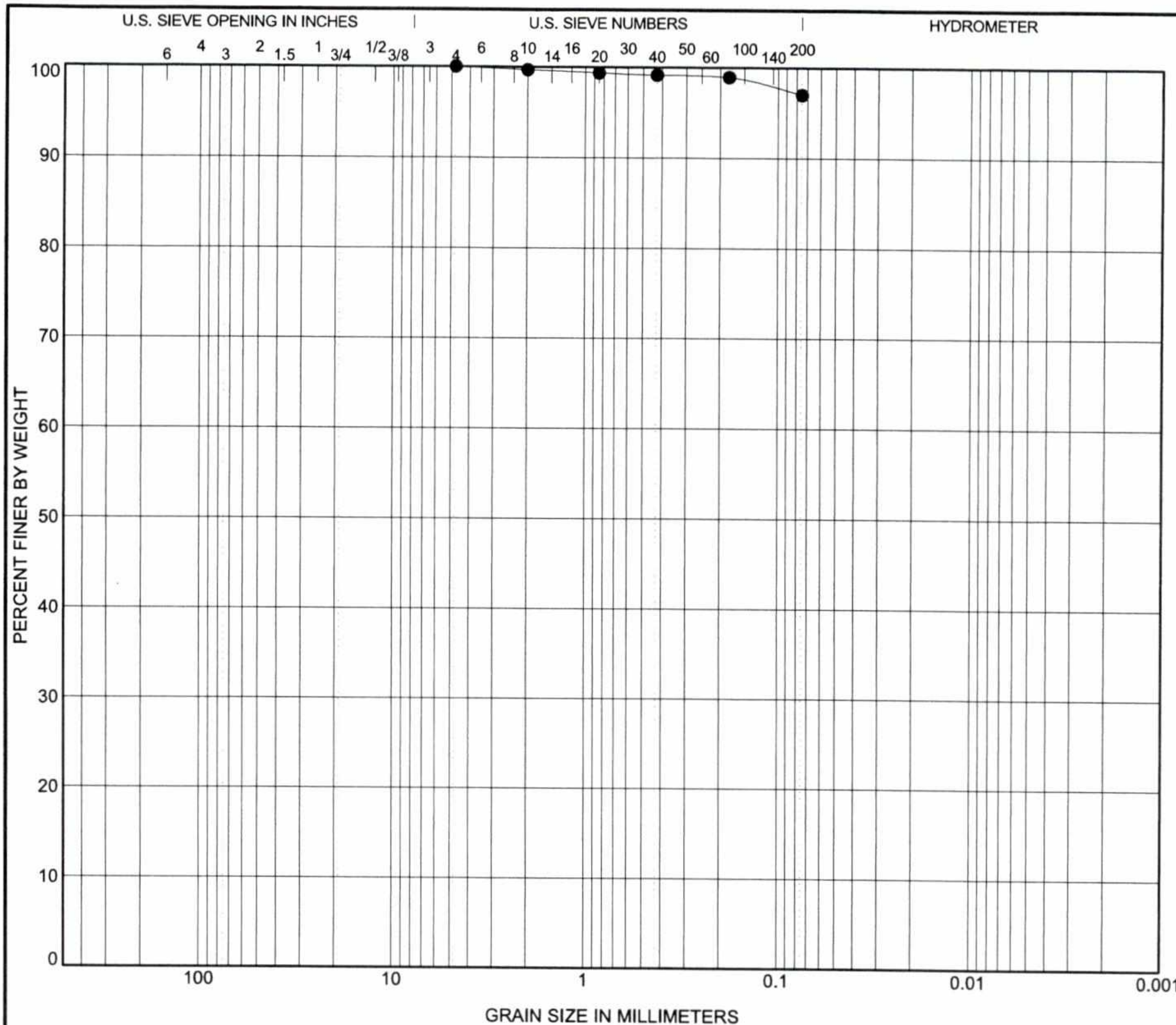
Location: See Drawing 550852-1

Number: 114-550852

Figure No. 7

BILLINGS LANDFILL LOGS.GPJ 3-29-12 TT_US GRAIN SIZE

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Specimen Identification	Classification	LL	PL	PI	Cc	Cu
DH-2 - (20 - 20.4 ft)	**LEAN CLAY(CL)**	**43**	**19**	**24**		

Specimen Identification	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
DH-2 - (20 - 20.4 ft)	**4.75**				**0**	**3**	**97**	

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Billings Landfill Phase V Expansion

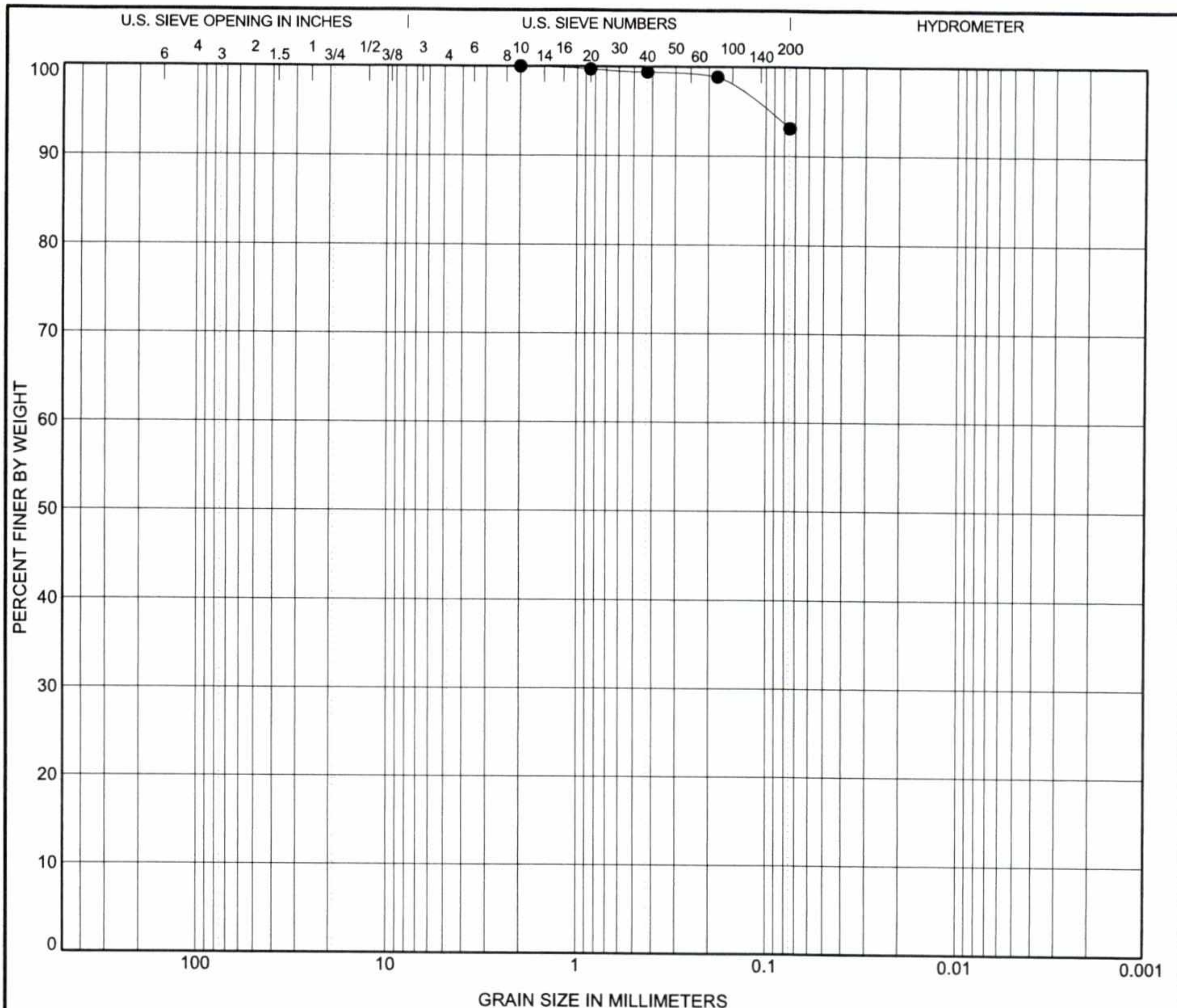
Location: See Drawing 550852-1

Number: 114-550852

Figure No. 8

BILLINGS LANDFILL LOGS.GPJ 3-29-12 TT_US GRAIN SIZE

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Specimen Identification	Classification	LL	PL	PI	Cc	Cu
DH-2 - (35 - 35.4 ft)	**LEAN CLAY(CL)**	**45**	**18**	**27**		

Specimen Identification	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
DH-2 - (35 - 35.4 ft)	**2**				**0**	**7**	**93**	

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Billings Landfill Phase V Expansion

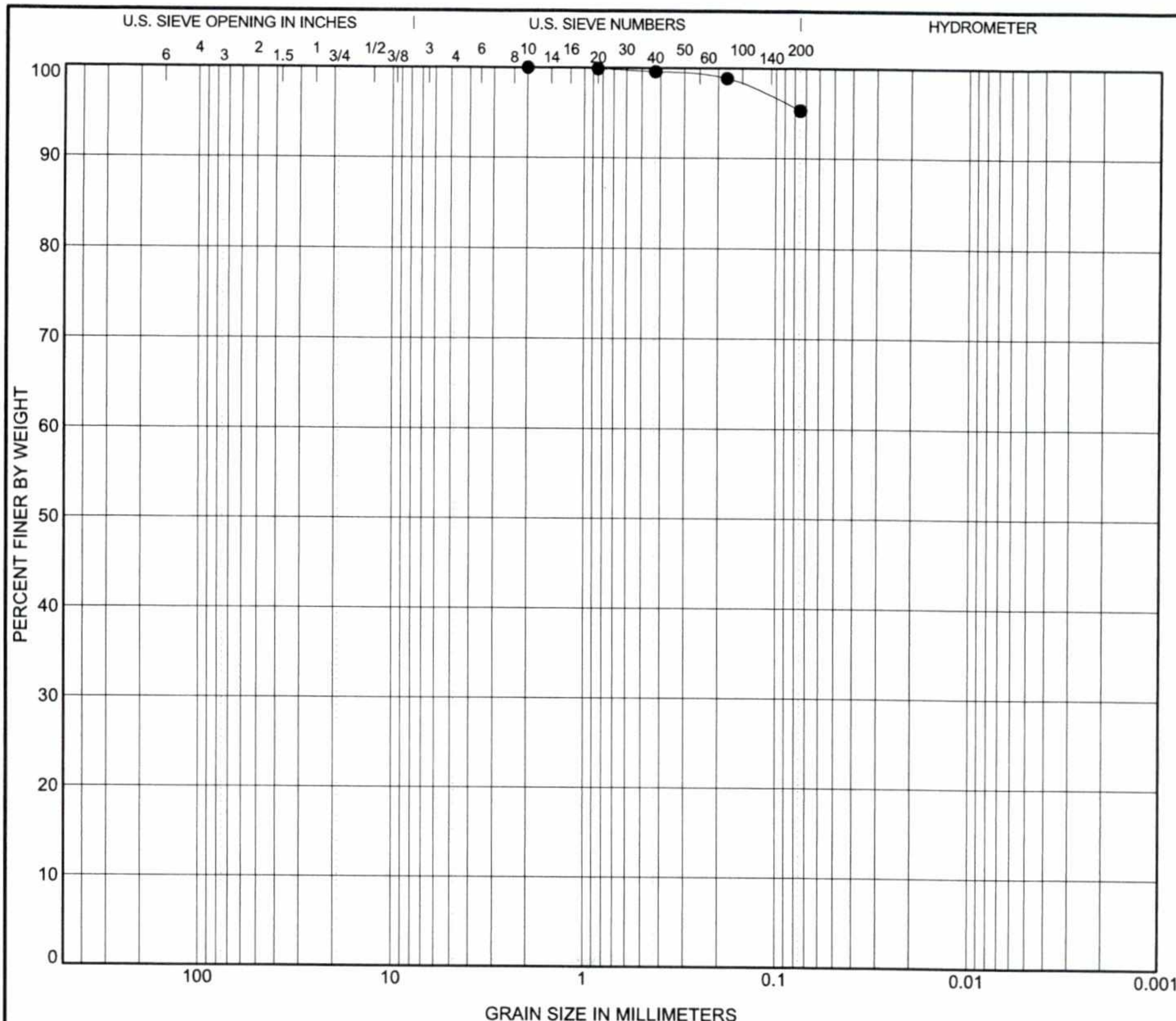
Location: See Drawing 550852-1

Number: 114-550852

Figure No. 9

BILLINGS LANDFILL LOGS.GPJ 3-29-12 TT_US GRAIN SIZE

Revised 1-23-08 (MAT)



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Specimen Identification	Classification	LL	PL	PI	Cc	Cu
DH-3 - (55 - 60 ft)	**LEAN CLAY(CL)**	**42**	**19**	**23**		

Specimen Identification	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
DH-3 - (55 - 60 ft)	**2**				**0**	**5**	**95**	

TETRA TECH

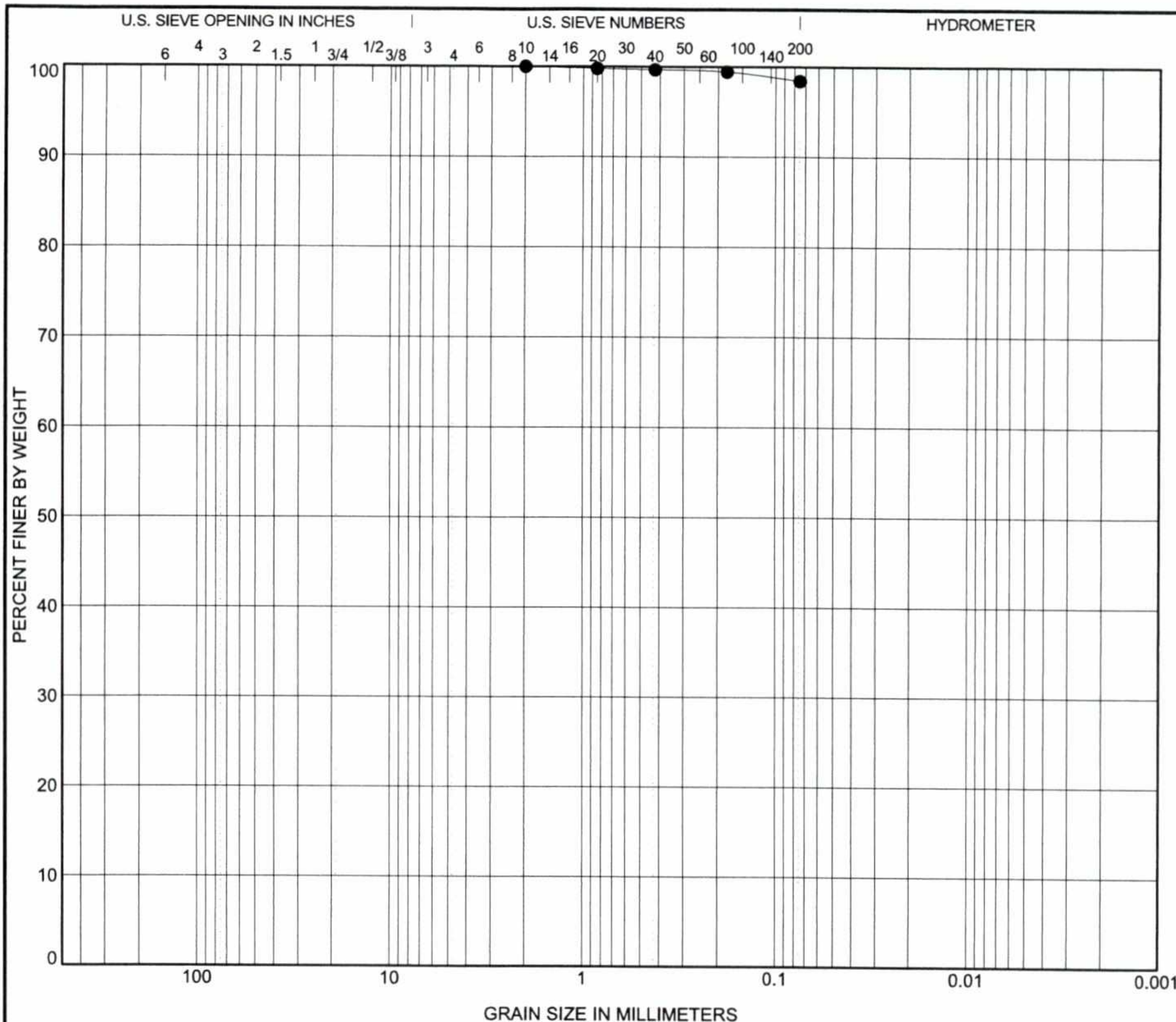
GRAIN SIZE DISTRIBUTION

Project: Billings Landfill Phase V Expansion

Location: See Drawing 550852-1

Number: 114-550852

Figure No. 10



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Specimen Identification	Classification	LL	PL	PI	Cc	Cu
DH-3 - (70 - 75 ft)	**LEAN CLAY(CL)**	**48**	**20**	**28**		

Specimen Identification	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
DH-3 - (70 - 75 ft)	**2**				**0**	**2**	**98**	

BILLINGS LANDFILL LOGS.GPJ 3-29-12 TT_US GRAIN SIZE

TETRA TECH

GRAIN SIZE DISTRIBUTION

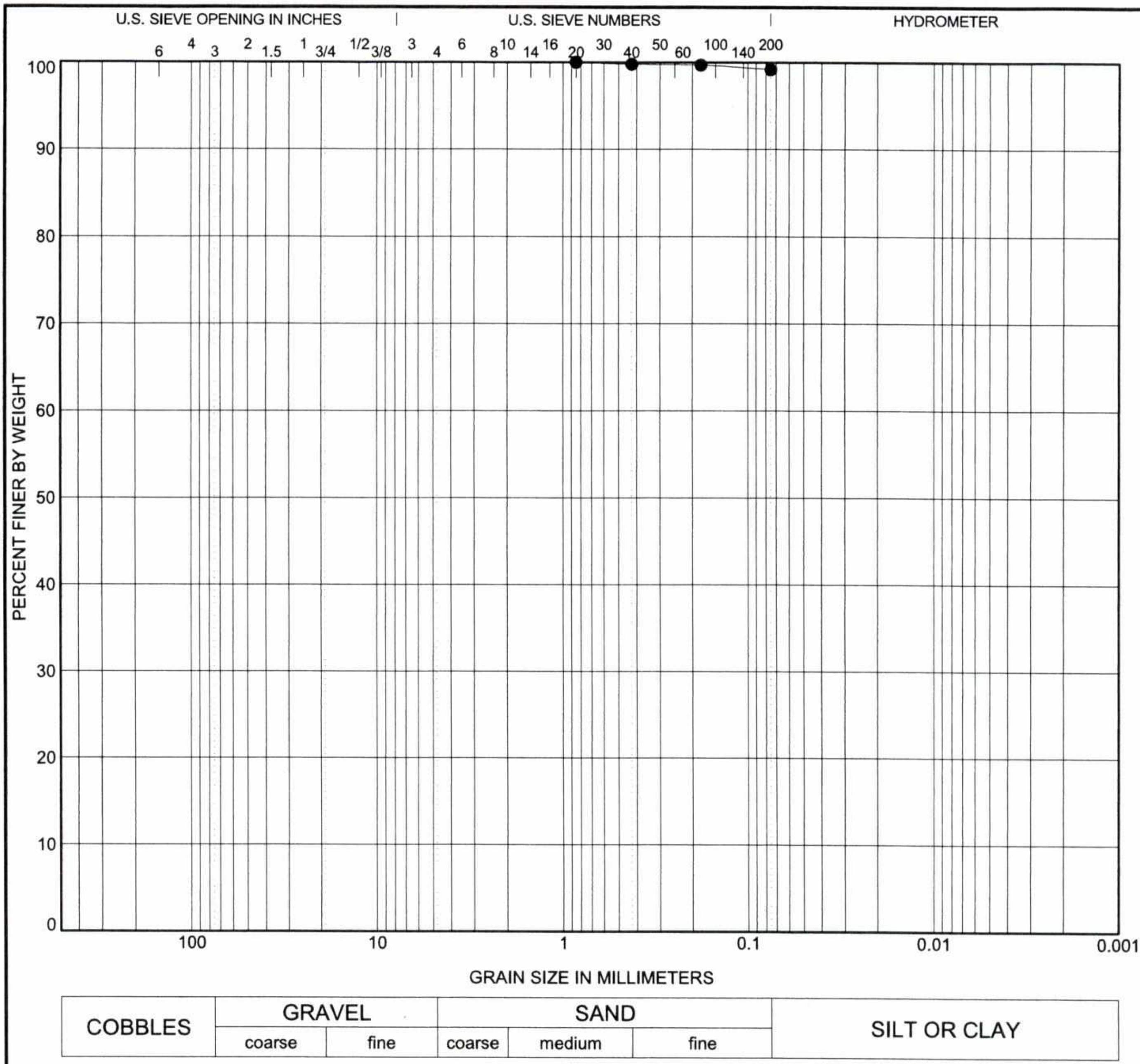
Project: Billings Landfill Phase V Expansion

Location: See Drawing 550852-1

Number: 114-550852

Figure No. 11

Revised 1-23-08 (MAT)



Specimen Identification	Classification	LL	PL	PI	Cc	Cu
DH-3 - (85 - 90 ft)	**FAT CLAY(CH)**	**55**	**22**	**33**		

Specimen Identification	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
DH-3 - (85 - 90 ft)	**0.85**				**0**	**1**	**99**	

TETRA TECH

GRAIN SIZE DISTRIBUTION

Project: Billings Landfill Phase V Expansion

Location: See Drawing 550852-1

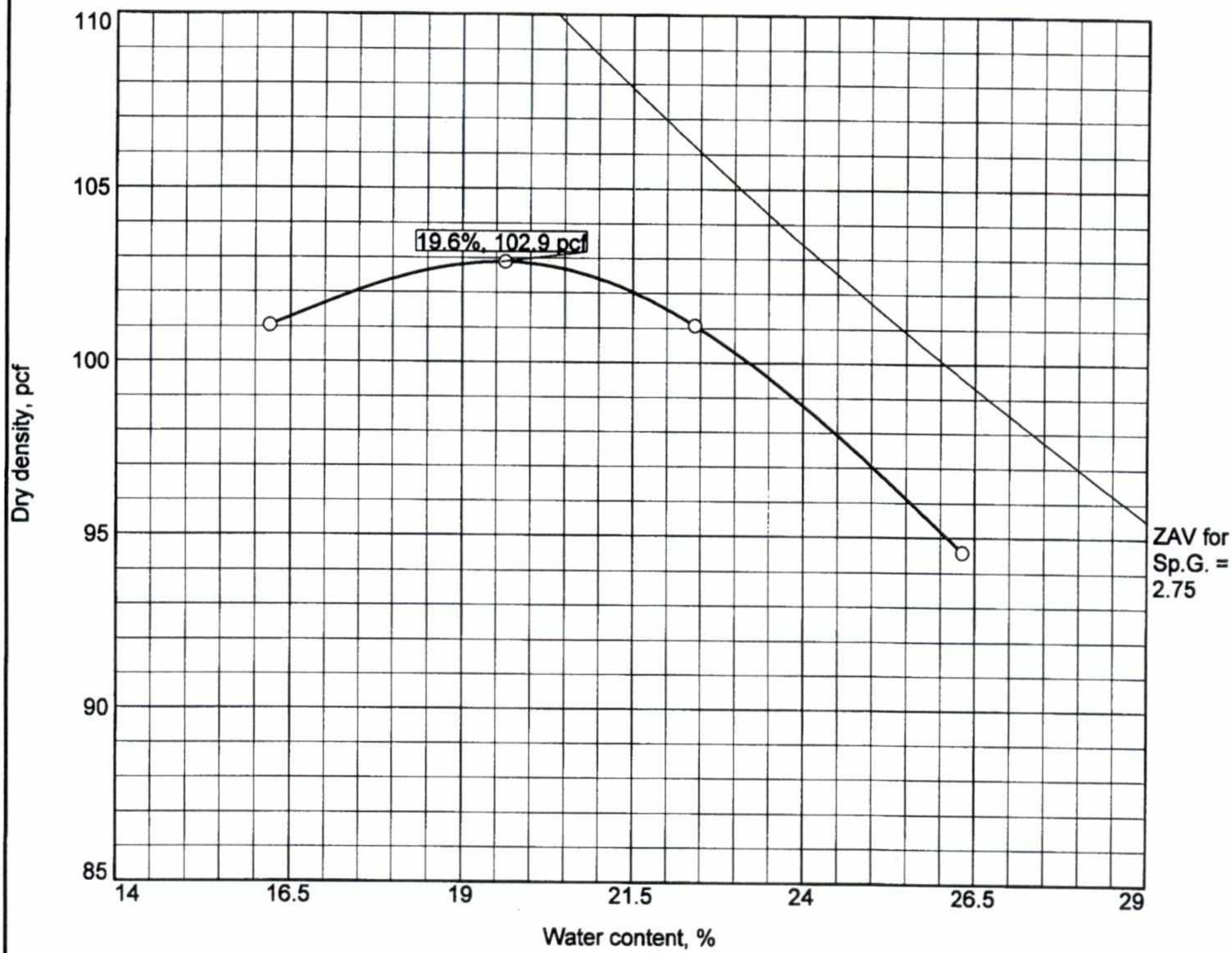
Number: 114-550852

Figure No. 12

BILLINGS LANDFILL LOGS.GPJ 3-29-12 TT_US GRAIN SIZE

Revised 1-23-08 (MAT)

Moisture Density Relationship



Test specification: ASTM D 698-07 Method A Standard

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > #4	% < No.200
	USCS	AASHTO						
15.0'-20.0'								

TEST RESULTS	MATERIAL DESCRIPTION
Maximum dry density = 102.9 pcf Optimum moisture = 19.6 %	Lean CLAY

Project No. 114-550852 **Client:** Great West Engineering
Project: Billings Landfill Phase V Expansion

○ **Source of Sample:** DH-1 **Depth:** 15.0'-20.0'

Tetra Tech, Inc.

Billings, MT

Remarks:

Figure 13

PERMEABILITY TEST REPORT

TEST DATA:

Specimen Height (cm): 5.08
Specimen Diameter (cm): 7.11
Dry Unit Weight (pcf): 97.9
Moisture Before Test (%): 19.7
Moisture After Test (%): 0.0
Run Number: 1 ● 2 ▲
Cell Pressure (psi): 65.0
Test Pressure(psi): 60.0
Back Pressure(psi): 57.9
Diff. Head (psi): 2.1
Flow Rate (cc/sec): 5.35 x 10^-4
Perm. (cm/sec): 4.64 x 10^-7

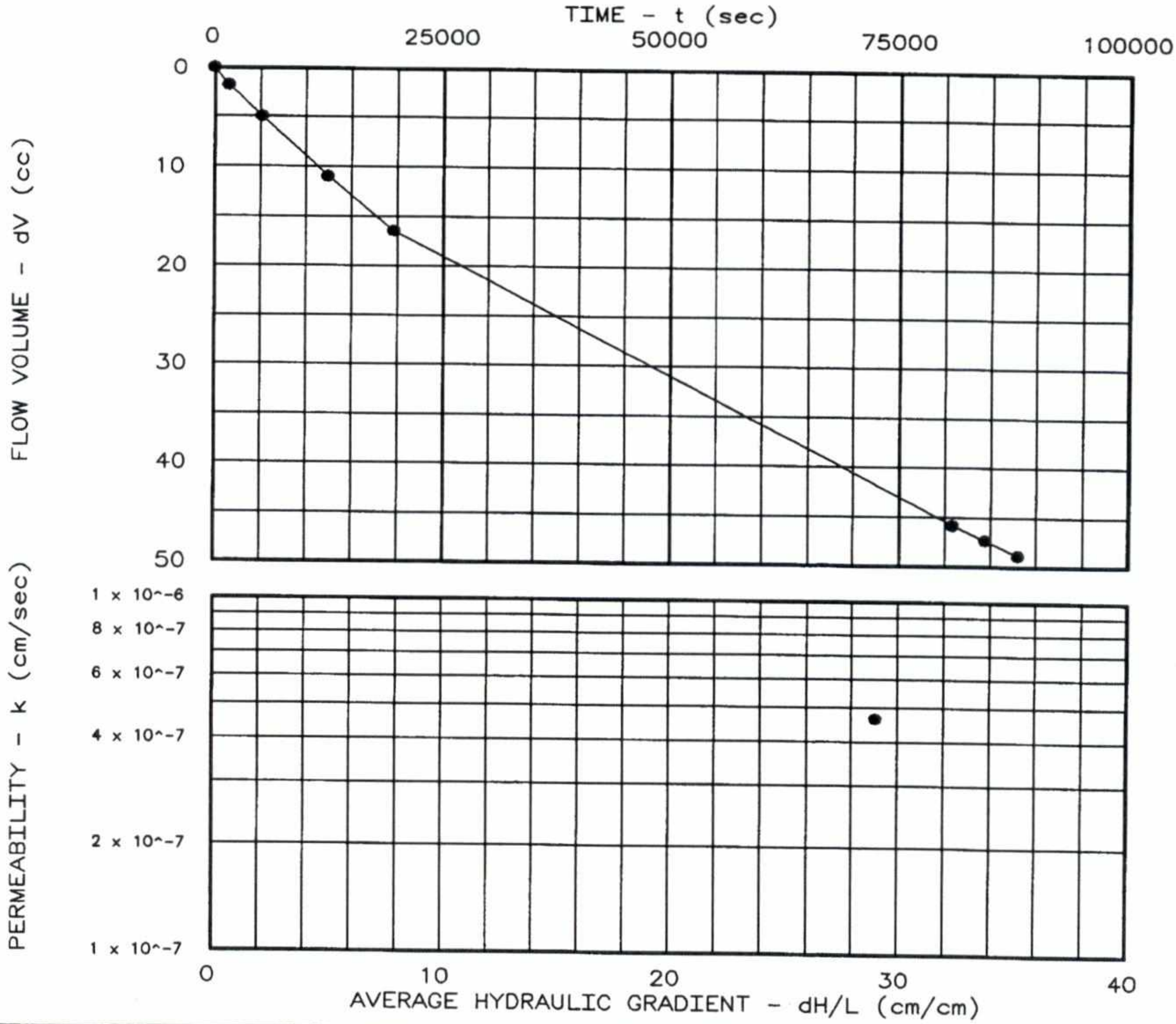
SAMPLE DATA:

Sample Identification: DH-1 15.0'-20.0'

Visual Description:

Remarks: Sp Gr 2.66 Por 0.4104

Maximum Dry Density (pcf): 102.9
Optimum Moisture Content (%): 19.6
ASTM(D698)
Percent Compaction: 95.1%
Permeameter type: Flexwall
Sample type: Remolded



Project: Billings Landfill Phase V Expansion
Location:
Date: 3/26/2012

PERMEABILITY TEST REPORT

TETRA TECH

Project No.: 114-550852
File No.: 229
Lab No.:
Tested by:
Checked by:
Test: CH - Constant head

PERMEABILITY TEST REPORT

TEST DATA:

Specimen Height (cm): 1.78
Specimen Diameter (cm): 3.56
Dry Unit Weight (pcf): 125.0
Moisture Before Test (%): 9.0
Moisture After Test (%): 0.0

Run Number:	1 ●	2 ▲
Cell Pressure (psi):	65.0	
Test Pressure(psi):	62.0	
Back Pressure(psi):	57.7	
Diff. Head (psi):	4.3	
Flow Rate (cc/sec):	1.01 x 10^-5	
Perm. (cm/sec):	5.94 x 10^-9	

SAMPLE DATA:

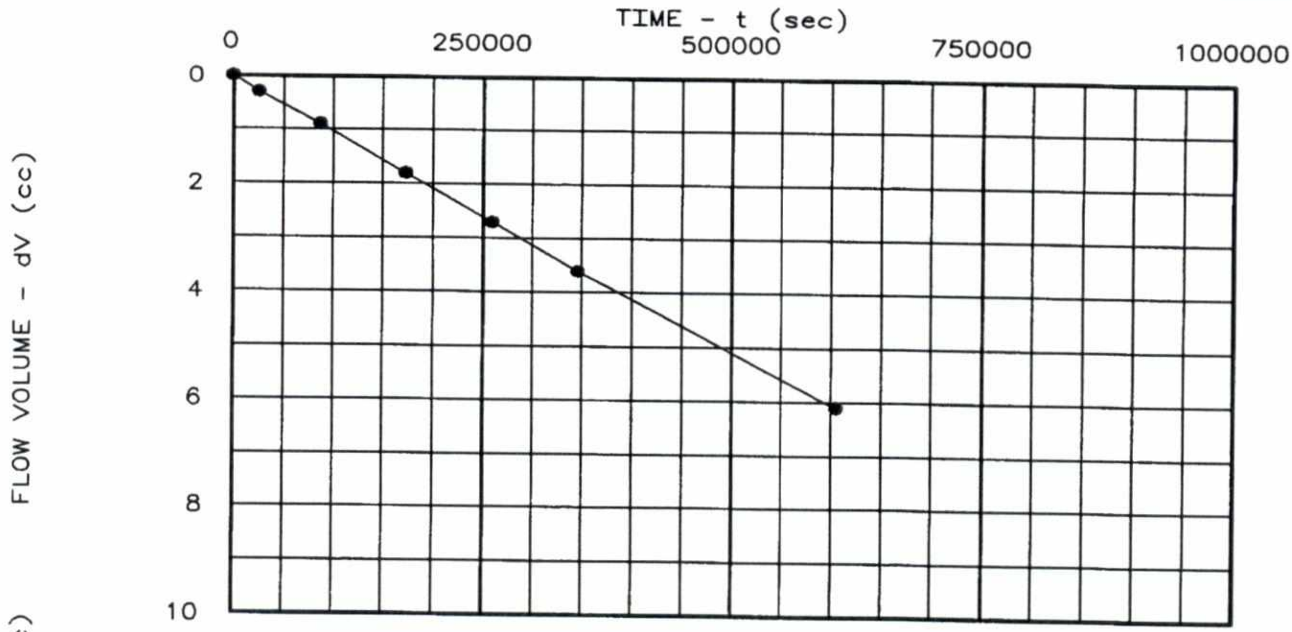
Sample Identification: DH-1 25.0'-30.7'

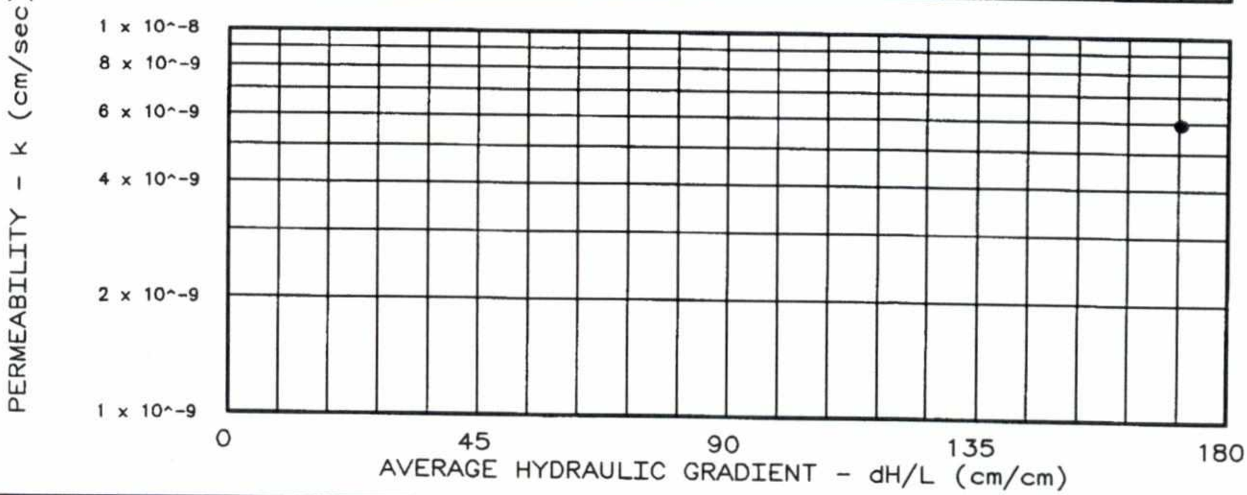
Visual Description:

Remarks: Sp Gr 2.70 Por 0.2583

Maximum Dry Density (pcf):
Optimum Moisture Content (%):

Percent Compaction:
Permeameter type: Flexwall
Sample type: Remolded





Project: Billings Landfill Phase V Expansion
Location:
Date: 3/19/12

Project No.: 114-550852
File No.: 225
Lab No.:
Tested by:
Checked by:
Test: CH - Constant head

PERMEABILITY TEST REPORT

TETRA TECH

PERMEABILITY TEST REPORT

TEST DATA:
Specimen Height (cm): 1.78
Specimen Diameter (cm): 3.56
Dry Unit Weight (pcf): 123.3
Moisture Before Test (%): 10.0
Moisture After Test (%): 0.0

Run Number:	1 ●	2 ▲
Cell Pressure (psi):	65.0	
Test Pressure(psi):	60.0	
Back Pressure(psi):	57.6	
Diff. Head (psi):	2.4	
Flow Rate (cc/sec):	6.59 x 10^-6	
Perm. (cm/sec):	7.12 x 10^-9	

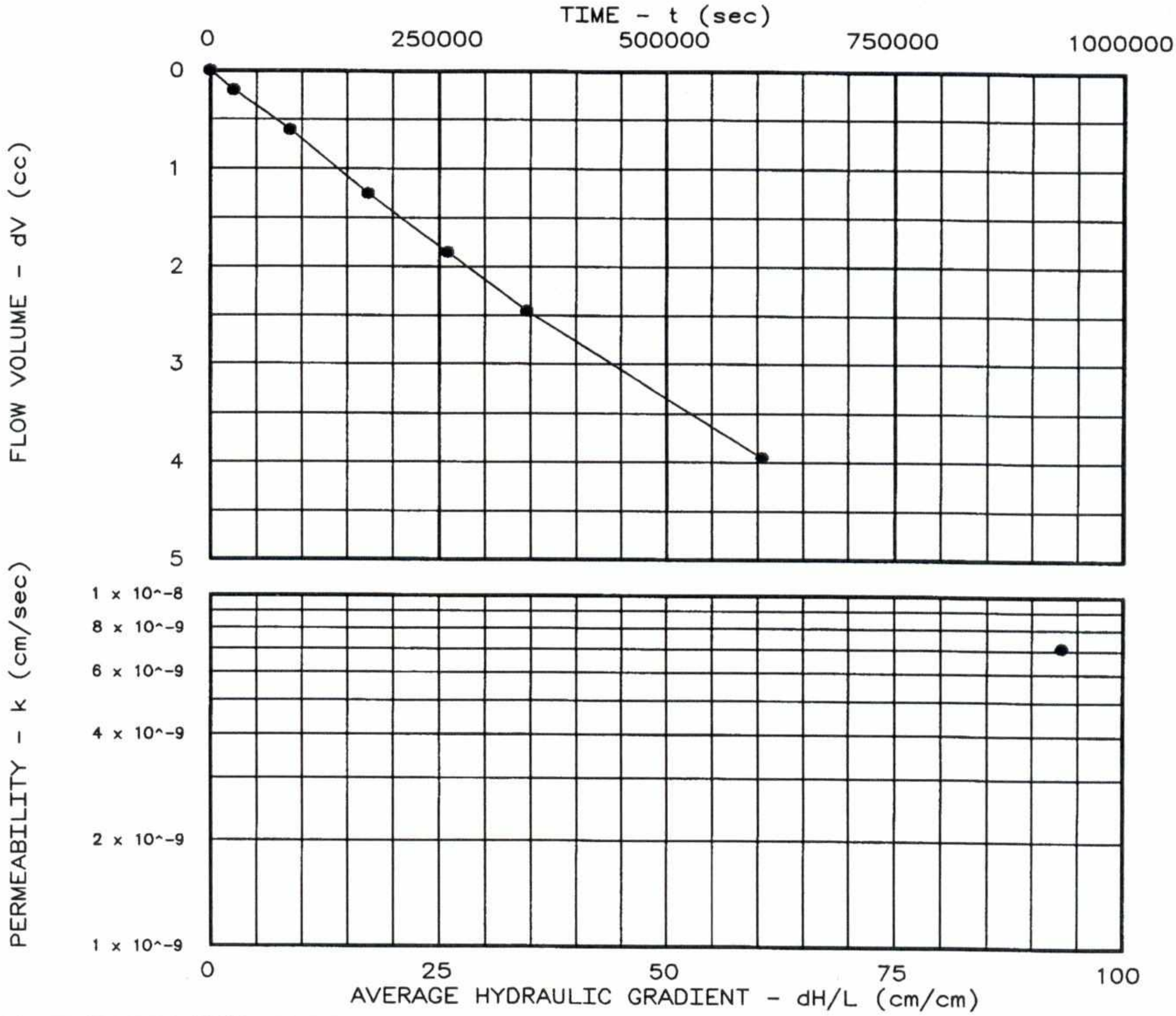
SAMPLE DATA:
Sample Identification: DH-1 35.0'-40.7'

Visual Description:

Remarks: Sp Gr 2.72 Por 0.2736

Maximum Dry Density (pcf):
Optimum Moisture Content (%):

Percent Compaction:
Permeameter type: Flexwall
Sample type: Remolded



Project: Billings Landfill Phase V Expansion
Location:
Date: 3/19/2012

PERMEABILITY TEST REPORT

TETRA TECH

Project No.: 114-550852
File No.: 226
Lab No.:
Tested by:
Checked by:
Test: CH - Constant head

PERMEABILITY TEST REPORT

TEST DATA:

Specimen Height (cm): 1.78
Specimen Diameter (cm): 3.56
Dry Unit Weight (pcf): 122.9
Moisture Before Test (%): 10.6
Moisture After Test (%): 0.0

Run Number:	1 ●	2 ▲
Cell Pressure (psi):	65.0	
Test Pressure(psi):	60.0	
Back Pressure(psi):	57.6	
Diff. Head (psi):	2.4	
Flow Rate (cc/sec):	2.40 x 10^-6	
Perm. (cm/sec):	2.56 x 10^-9	

SAMPLE DATA:

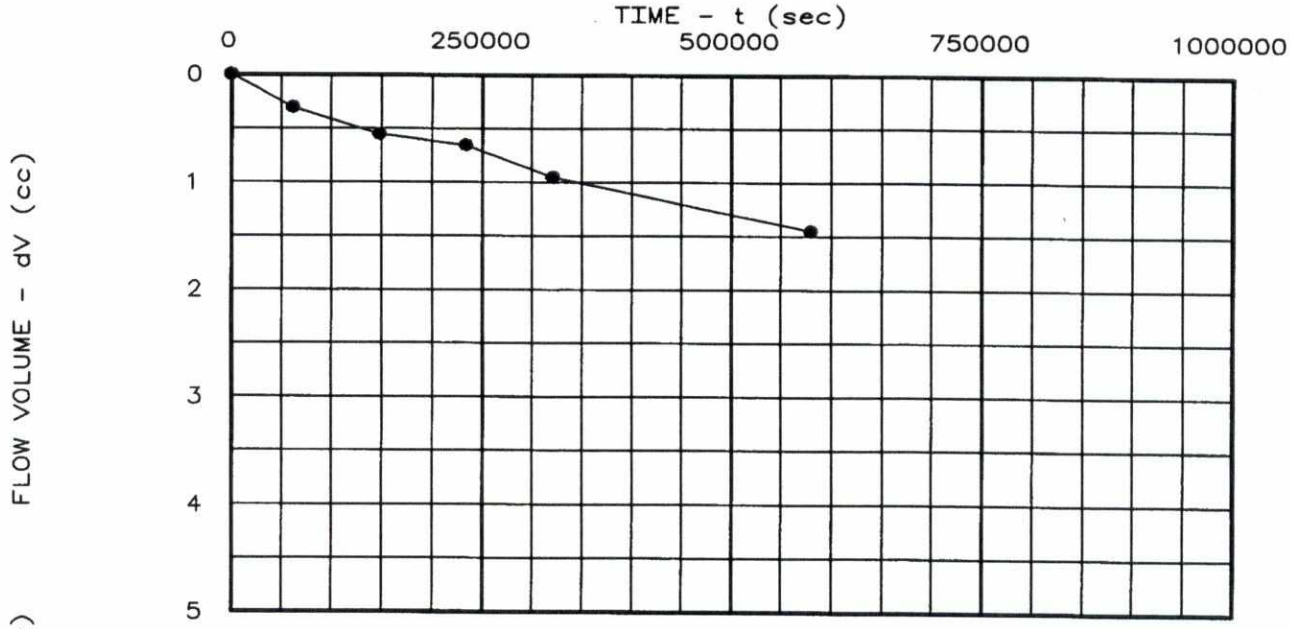
Sample Identification: DH-1 45.0'-45.6'

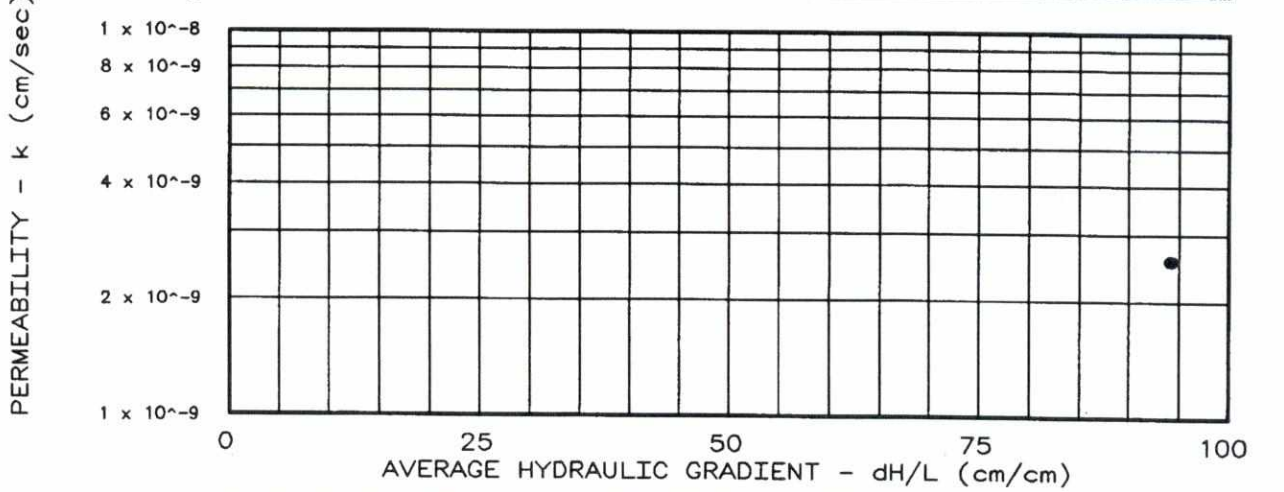
Visual Description:

Remarks: Sp Gr 2.73 Por 0.2791

Maximum Dry Density (pcf):
Optimum Moisture Content (%):

Percent Compaction:
Permeameter type: Flexwall
Sample type: Remolded





Project: Billings Landfill Phase V Expansion	Project No.: 114-550852
Location:	File No.: 224
Date: 3/19/2012	Lab No.:
PERMEABILITY TEST REPORT	Tested by:
	Checked by:
TETRA TECH	Test: CH - Constant head

PERMEABILITY TEST REPORT

TEST DATA:

Specimen Height (cm): 1.78
Specimen Diameter (cm): 3.56
Dry Unit Weight (pcf): 120.1
Moisture Before Test (%): 9.9
Moisture After Test (%): 0.0
Run Number: 1 ● 2 ▲
Cell Pressure (psi): 65.0
Test Pressure(psi): 60.0
Back Pressure(psi): 57.3
Diff. Head (psi): 2.7
Flow Rate (cc/sec): 8.28 x 10^-6
Perm. (cm/sec): 7.87 x 10^-9

SAMPLE DATA:

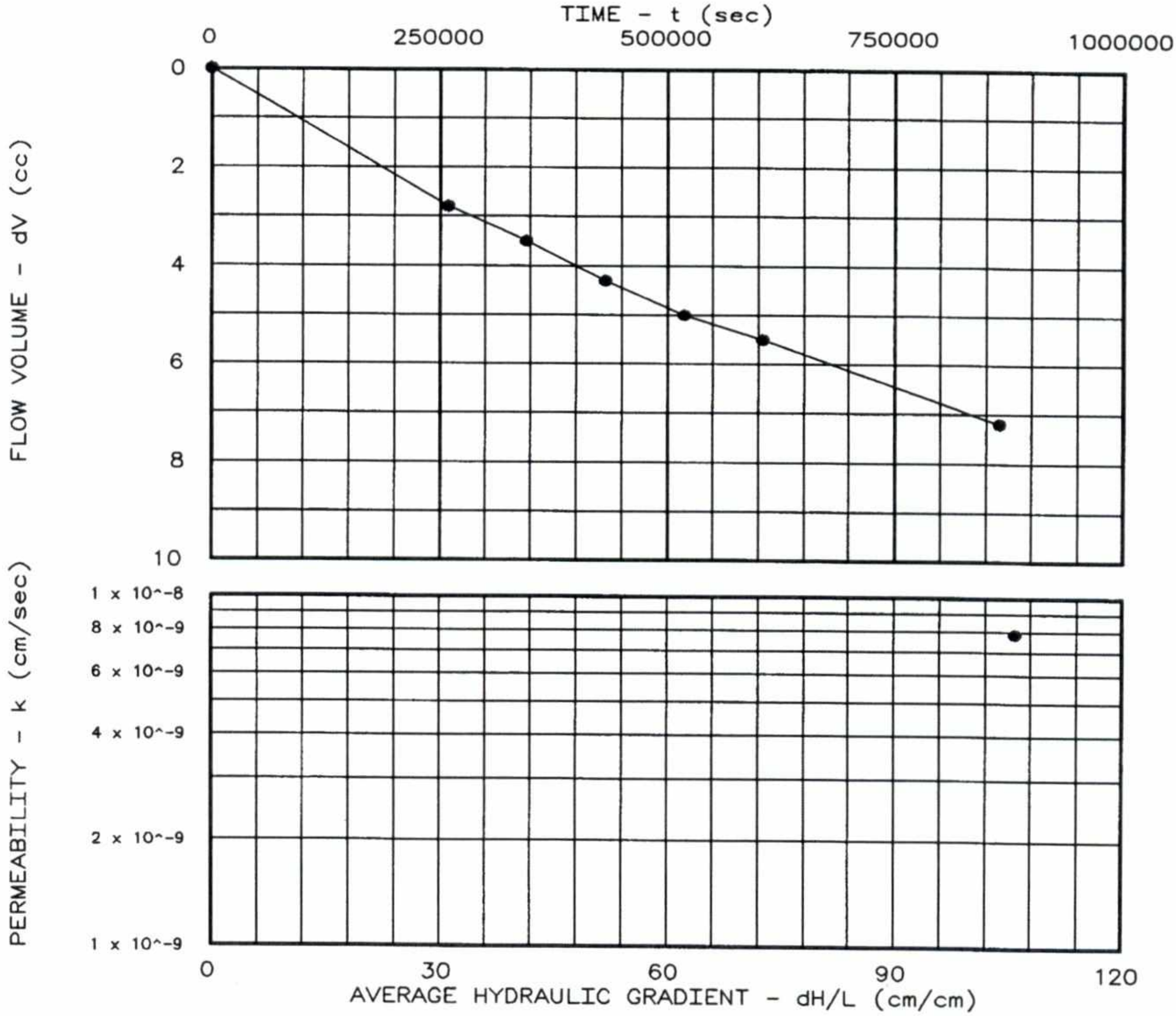
Sample Identification: DH-2 20.0'-25.4'

Visual Description:

Remarks: Sp Gr 2.70 Por 0.2875

Maximum Dry Density (pcf):
Optimum Moisture Content (%):

Percent Compaction:
Permeameter type: Flexwall
Sample type: Remolded



Project: Billings Landfill Phase V Expansion
Location:
Date: 3/26/2012

PERMEABILITY TEST REPORT

TETRA TECH

Project No.: 114-550852
File No.: 228
Lab No.:
Tested by:
Checked by:
Test: CH - Constant head

PERMEABILITY TEST REPORT

TEST DATA:

Specimen Height (cm): 1.78
Specimen Diameter (cm): 3.56
Dry Unit Weight (pcf): 125.8
Moisture Before Test (%): 7.3
Moisture After Test (%): 0.0
Run Number: 1 ● 2 ▲
Cell Pressure (psi): 65.0
Test Pressure(psi): 60.0
Back Pressure(psi): 57.3
Diff. Head (psi): 2.7
Flow Rate (cc/sec): 6.28 x 10^-6
Perm. (cm/sec): 5.89 x 10^-9

SAMPLE DATA:

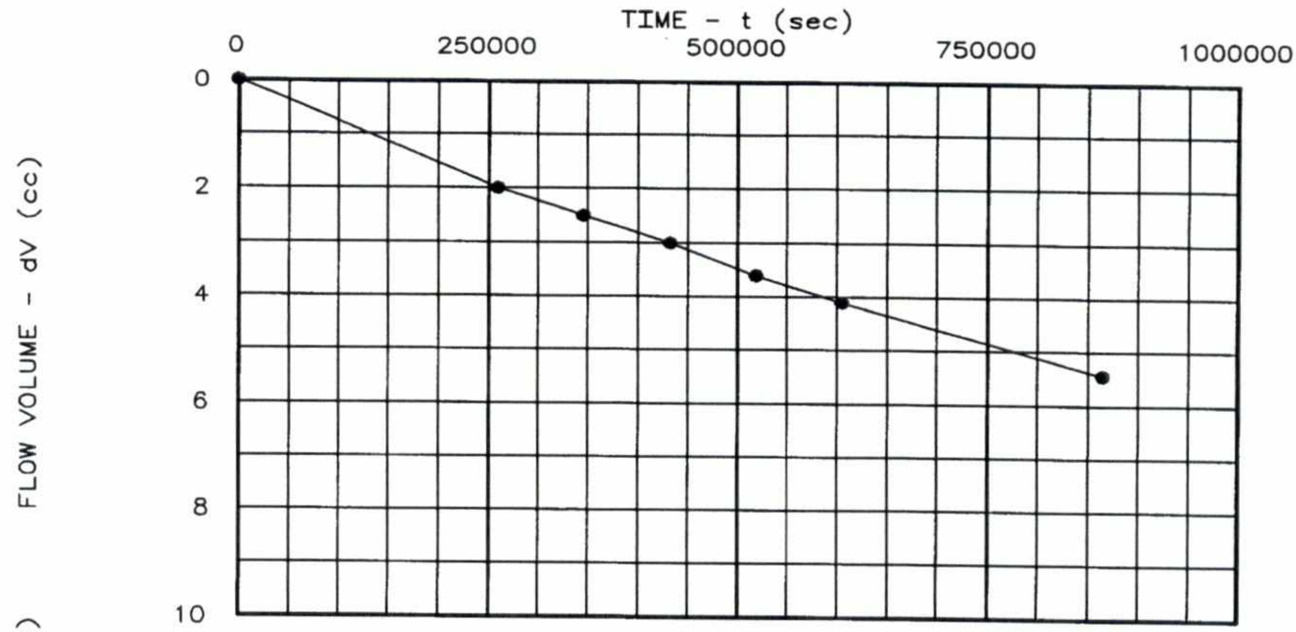
Sample Identification: DH-2 35.0'-35.4'

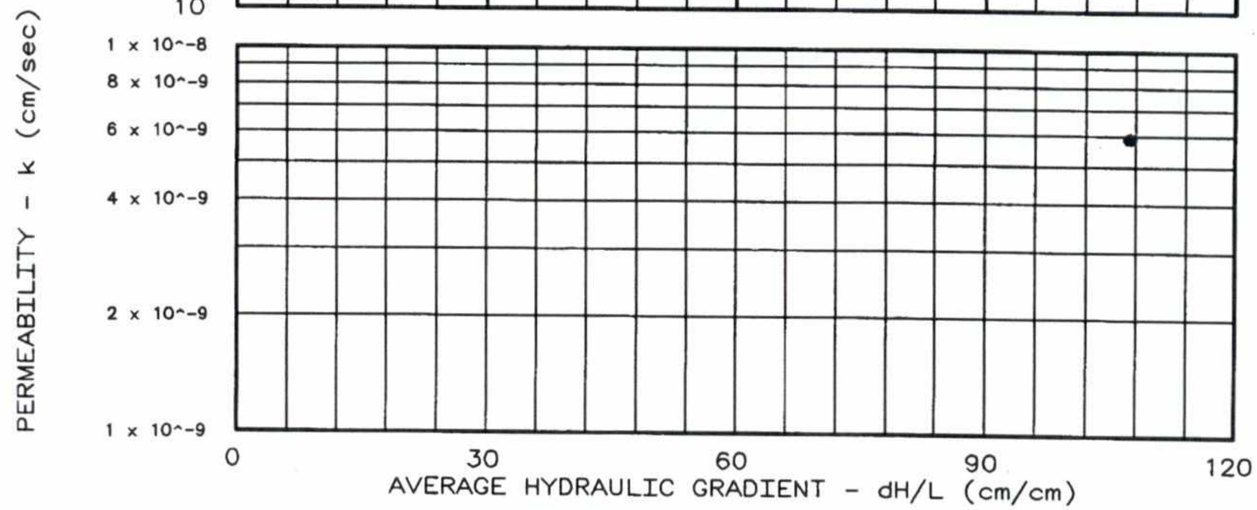
Visual Description:

Remarks: Sp Gr 2.72 Por 0.2594

Maximum Dry Density (pcf):
Optimum Moisture Content (%):

Percent Compaction:
Permeameter type: Flexwall
Sample type: Remolded





Project: Billings Landfill Phase V Expansion
Location:
Date: 3/26/2012

PERMEABILITY TEST REPORT

TETRA TECH

Project No.: 114-550852
File No.: 227
Lab No.:
Tested by:
Checked by:
Test: CH - Constant head

PERMEABILITY TEST REPORT

TEST DATA:

Specimen Height (cm): 2.16
Specimen Diameter (cm): 6.07
Dry Unit Weight (pcf): 146.3
Moisture Before Test (%): 6.5
Moisture After Test (%): 0.0
Run Number: 1 ● 2 ▲
Cell Pressure (psi): 65.0
Test Pressure(psi): 60.0
Back Pressure(psi): 57.4
Diff. Head (psi): 2.6
Flow Rate (cc/sec): 9.27 x 10^-8
Perm. (cm/sec): 3.83 x 10^-11

SAMPLE DATA:

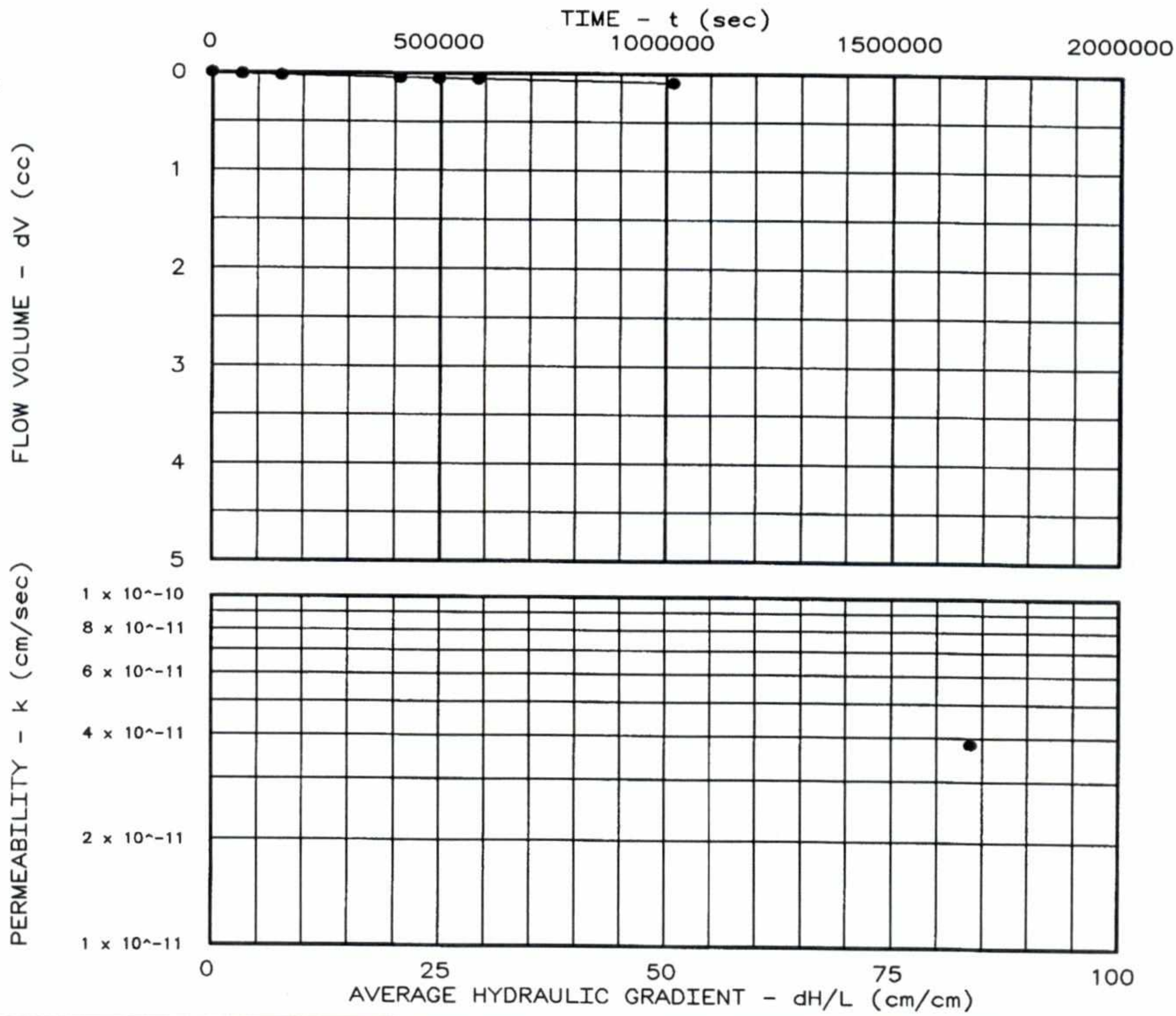
Sample Identification: DH-3 55'-60'

Visual Description:

Remarks: Sp Gr 2.73 Por 0.1417

Maximum Dry Density (pcf):
Optimum Moisture Content (%):

Percent Compaction:
Permeameter type: Flexwall
Sample type: Core



Project: Billings Landfill Phase V Expansion
Location:
Date: 3/12/12

PERMEABILITY TEST REPORT

TETRA TECH

Project No.: 114-550852
File No.: 222
Lab No.:
Tested by:
Checked by:
Test: CH - Constant head

PERMEABILITY TEST REPORT

TEST DATA:

Specimen Height (cm): 2.20
Specimen Diameter (cm): 6.10
Dry Unit Weight (pcf): 138.7
Moisture Before Test (%): 7.3
Moisture After Test (%): 0.0

Run Number:	1 ●	2 ▲
Cell Pressure (psi):	65.0	
Test Pressure(psi):	60.0	
Back Pressure(psi):	57.6	
Diff. Head (psi):	2.4	
Flow Rate (cc/sec):	1.61 x 10^-7	
Perm. (cm/sec):	7.16 x 10^-11	

SAMPLE DATA:

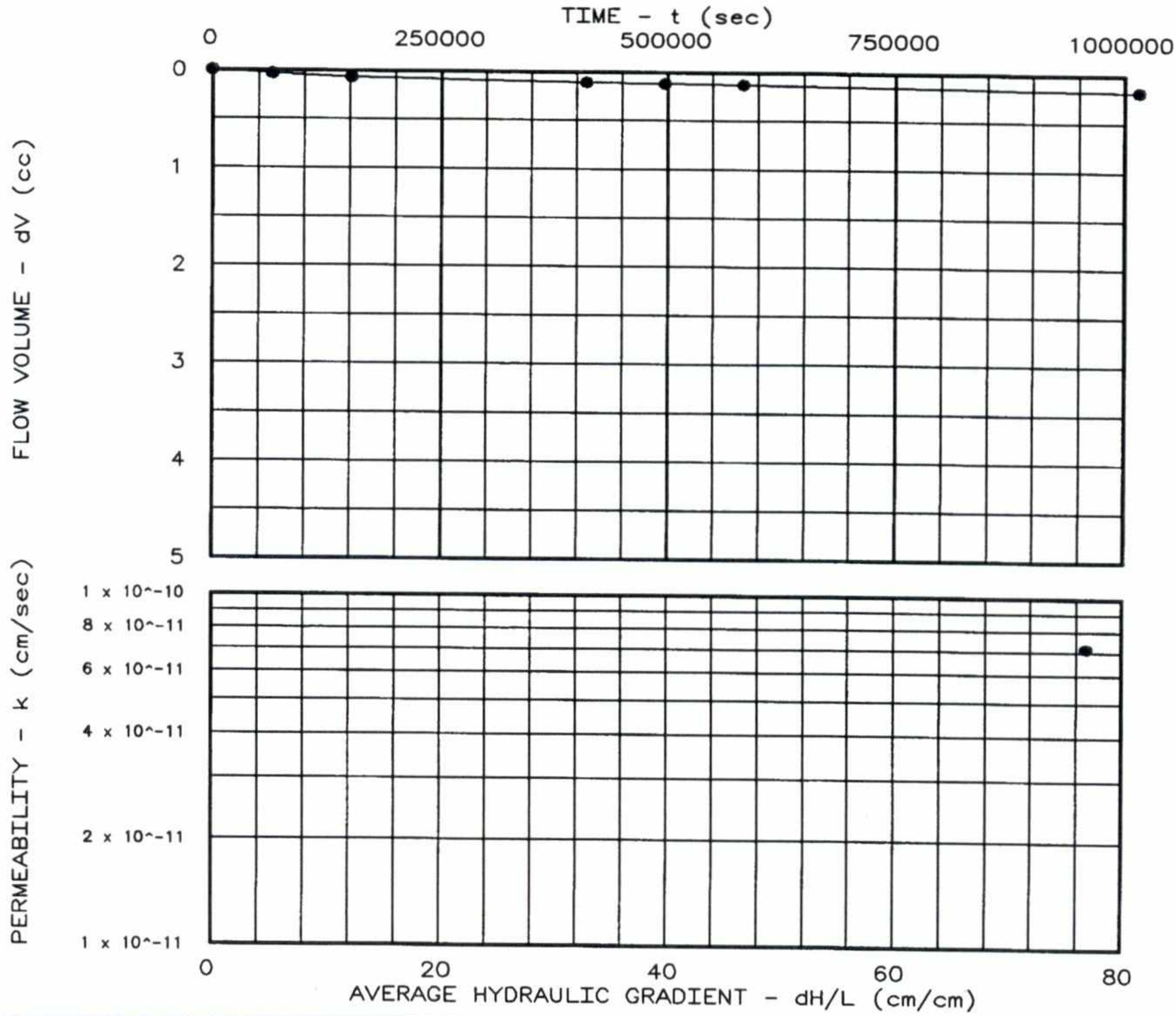
Sample Identification: DH-3 70'-75'

Visual Description:

Remarks: Sp Gr 2.73 Por 0.1860

Maximum Dry Density (pcf):
Optimum Moisture Content (%):

Percent Compaction:
Permeameter type:
Sample type: Core



Project: Billings Landfill Phase V Expansion
Location:
Date:

PERMEABILITY TEST REPORT

TETRA TECH

Project No.: 114-550852
File No.: 221
Lab No.:
Tested by:
Checked by:
Test: CH - Constant head

PERMEABILITY TEST REPORT

TEST DATA:

Specimen Height (cm): 2.22
Specimen Diameter (cm): 6.10
Dry Unit Weight (pcf): 137.5
Moisture Before Test (%): 7.6
Moisture After Test (%): 0.0
Run Number: 1 ● 2 ▲
Cell Pressure (psi): 65.0
Test Pressure(psi): 60.0
Back Pressure(psi): 57.3
Diff. Head (psi): 2.7
Flow Rate (cc/sec): 5.39 x 10^-8
Perm. (cm/sec): 2.19 x 10^-11

SAMPLE DATA:

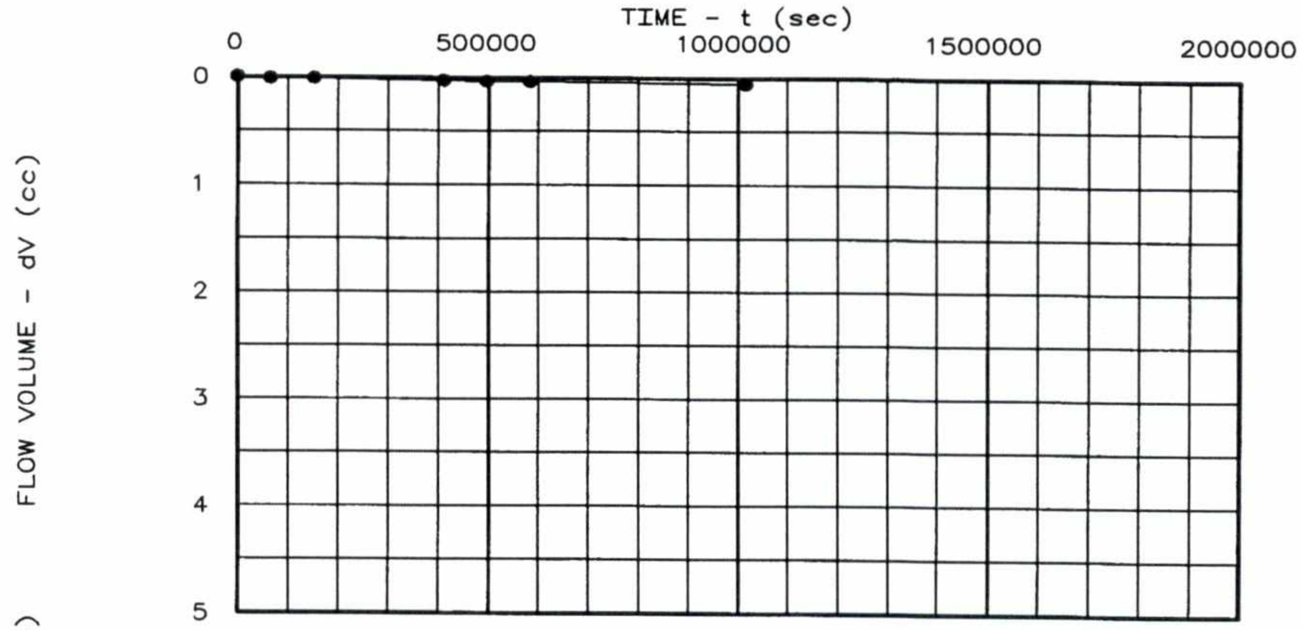
Sample Identification: DH-3 85'-90'

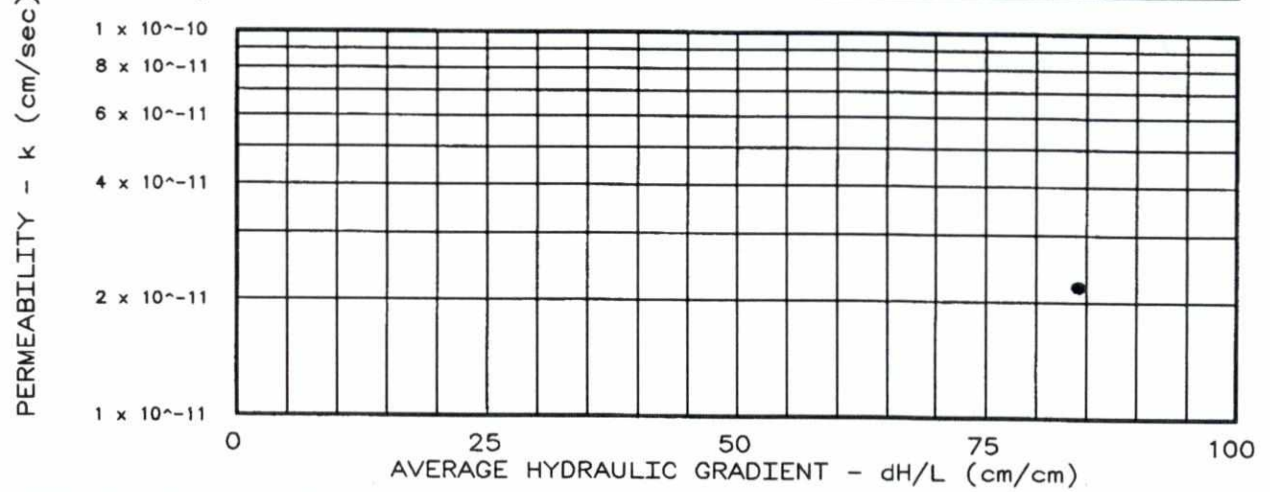
Visual Description:

Remarks: Sp Gr 2.73 Por 0.1933

Maximum Dry Density (pcf):
Optimum Moisture Content (%):

Percent Compaction:
Permeameter type: Flexwall
Sample type: Core





Project: Billings Landfill Phase V Expansion
Location:
Date: 3/12/12

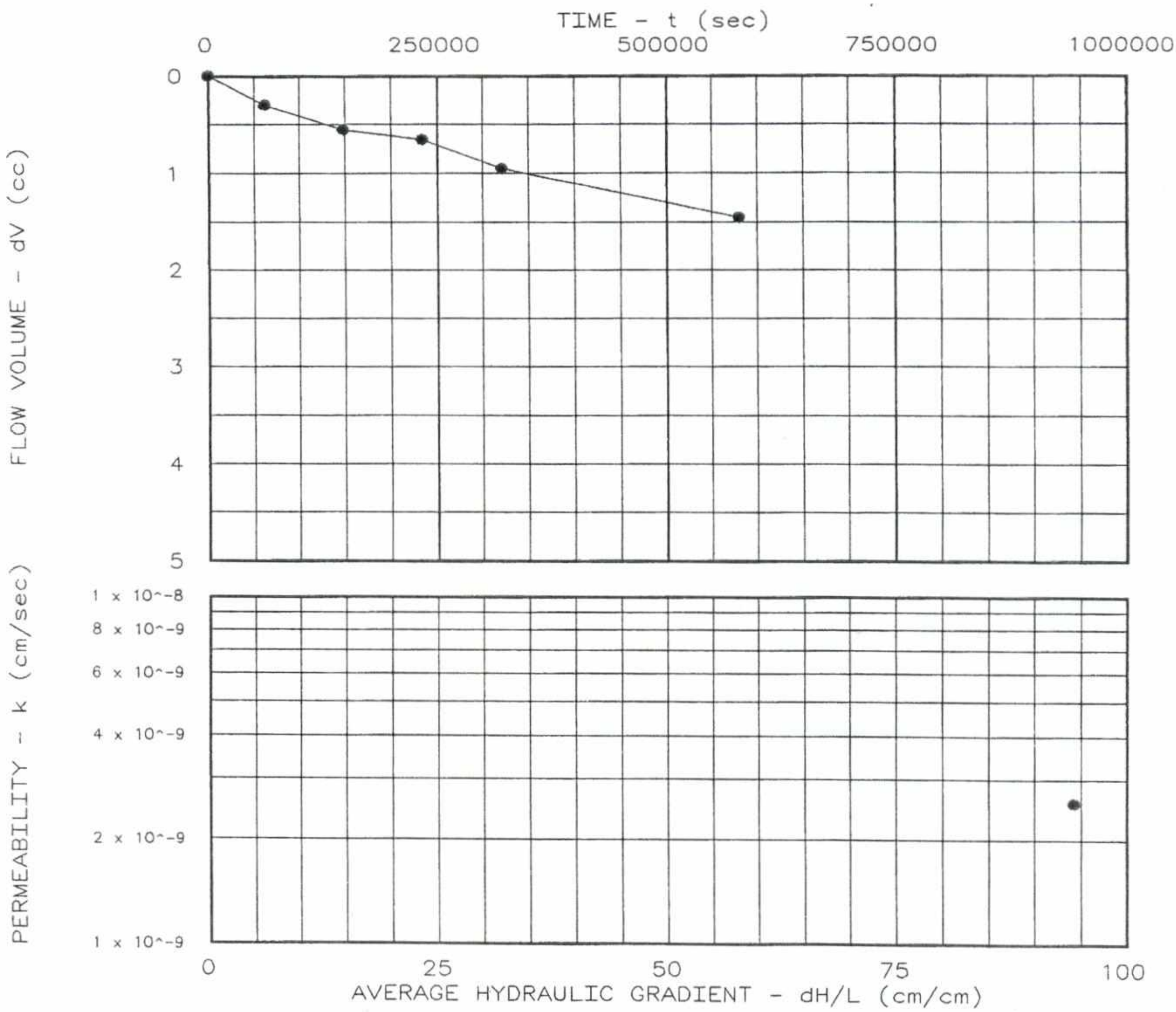
PERMEABILITY TEST REPORT

TETRA TECH

Project No.: 114-550852
File No.: 223
Lab No.:
Tested by:
Checked by:
Test: CH - Constant head

PERMEABILITY TEST REPORT

TEST DATA:			SAMPLE DATA:
Specimen Height (cm): 1.78			Sample Identification: DH-1 45.0'-45.6'
Specimen Diameter (cm): 3.56			
Dry Unit Weight (pcf): 122.9			Visual Description:
Moisture Before Test (%): 10.6			
Moisture After Test (%): 0.0			Remarks:
Run Number:	1 ●	2 ▲	
Cell Pressure (psi):	65.0		Maximum Dry Density (pcf):
Test Pressure(psi):	60.0		Optimum Moisture Content (%):
Back Pressure(psi):	57.6		
Diff. Head (psi):	2.4		Percent Compaction:
Flow Rate (cc/sec):	2.40 x 10^-6		Permeameter type: Flexwall
Perm. (cm/sec):	2.56 x 10^-9		Sample type: Remolded



Project: BILLINGS LANDFILL EXPANSION	Project No.: 114-550852
Location:	File No.: 224
Date: 3/19/2012	Lab No.:
PERMEABILITY TEST REPORT	Tested by:
TETRA TECH	Checked by:
	Test: CH - Constant head

PERMEABILITY TEST REPORT

TEST DATA:

Specimen Height (cm): 1.78
Specimen Diameter (cm): 3.56
Dry Unit Weight (pcf): 123.3
Moisture Before Test (%): 10.0
Moisture After Test (%): 0.0
Run Number: 1 ● 2 ▲
Cell Pressure (psi): 65.0
Test Pressure(psi): 60.0
Back Pressure(psi): 57.6
Diff. Head (psi): 2.4
Flow Rate (cc/sec): 6.59 x 10^-6
Perm. (cm/sec): 7.12 x 10^-9

SAMPLE DATA:

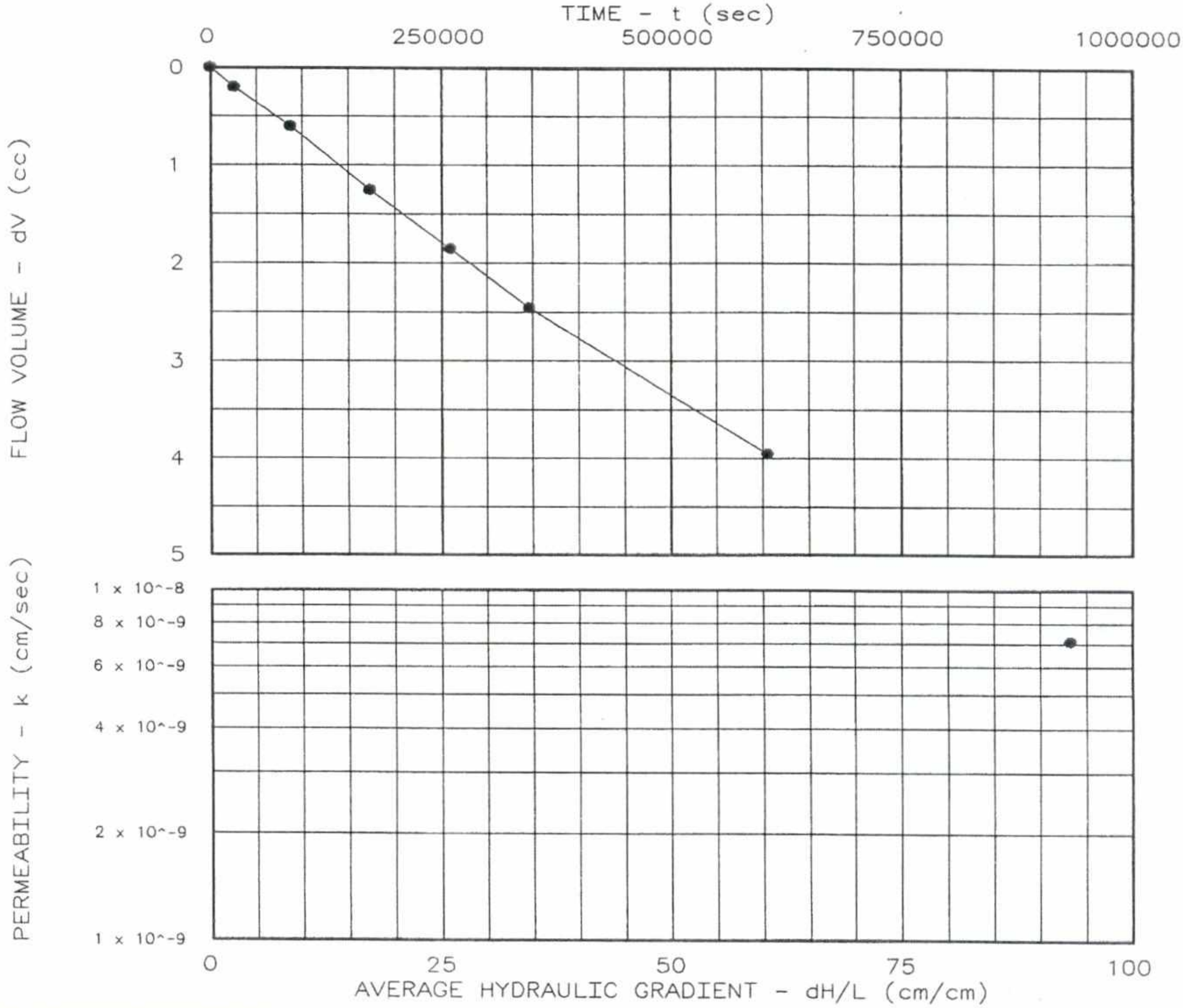
Sample Identification: DH-1 35.0'-40.7'

Visual Description:

Remarks:

Maximum Dry Density (pcf):
Optimum Moisture Content (%):

Percent Compaction:
Permeameter type: Flexwall
Sample type: Remolded



Project: BILLINGS LANDFILL EXPANSION
Location:
Date: 3/19/2012

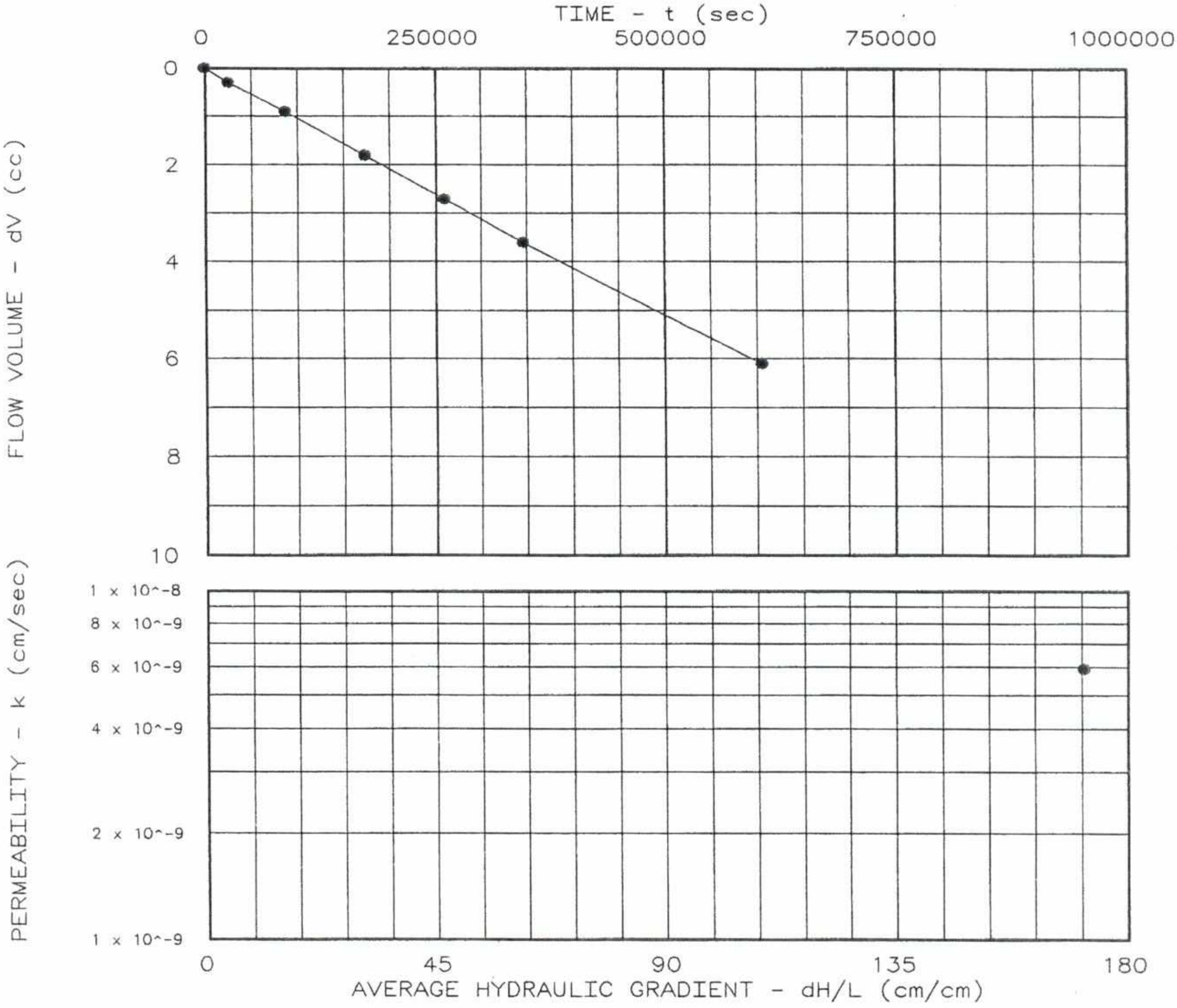
PERMEABILITY TEST REPORT

TETRA TECH

Project No.: 114-550852
File No.: 226
Lab No.:
Tested by:
Checked by:
Test: CH - Constant head

PERMEABILITY TEST REPORT

TEST DATA:			SAMPLE DATA:
Specimen Height (cm): 1.78			Sample Identification: DH-1 25.0'-30.7'
Specimen Diameter (cm): 3.56			
Dry Unit Weight (pcf): 125.0			Visual Description:
Moisture Before Test (%): 9.0			
Moisture After Test (%): 0.0			Remarks:
Run Number:	1 ●	2 ▲	
Cell Pressure (psi):	65.0		Maximum Dry Density (pcf):
Test Pressure(psi):	62.0		Optimum Moisture Content (%):
Back Pressure(psi):	57.7		
Diff. Head (psi):	4.3		Percent Compaction:
Flow Rate (cc/sec):	1.01 x 10^-5		Permeameter type: Flexwall
Perm. (cm/sec):	5.94 x 10^-9		Sample type: Remolded



Project: BILLINGS LANDFILL EXPANSION	Project No.: 114-550852
Location:	File No.: 225
Date: 3/19/12	Lab No.:
	Tested by:
PERMEABILITY TEST REPORT	Checked by:
TETRA TECH	Test: CH - Constant head

TETRA TECH

April 13, 2012

Mr. Bruce Siegmund
Great West Engineering
PO Box 4817
Helena, Montana 59604

Delivered via email

SUBJECT: Additional Test Results and Historical Data
Billings Landfill Phase V Expansion
Billings, Montana
Tetra Tech Project No. 114-550852

Dear Mr. Siegmund:

At your request, we have performed hydrometer testing and researched previous geotechnical investigations performed for the Billings Landfill for your use in preparing models for the City of Billings. Attached are the results for hydrometer testing, "Preliminary Subsurface Soils Investigation – Billings Sanitary Landfill" dated August 17, 1977, and "Billings Landfill Field Exploration Services" dated August 14, 1990.

If you have any questions regarding this information, please contact us. We appreciate the opportunity to provide geotechnical engineering services to you on this project.

Respectfully submitted,

Tetra Tech

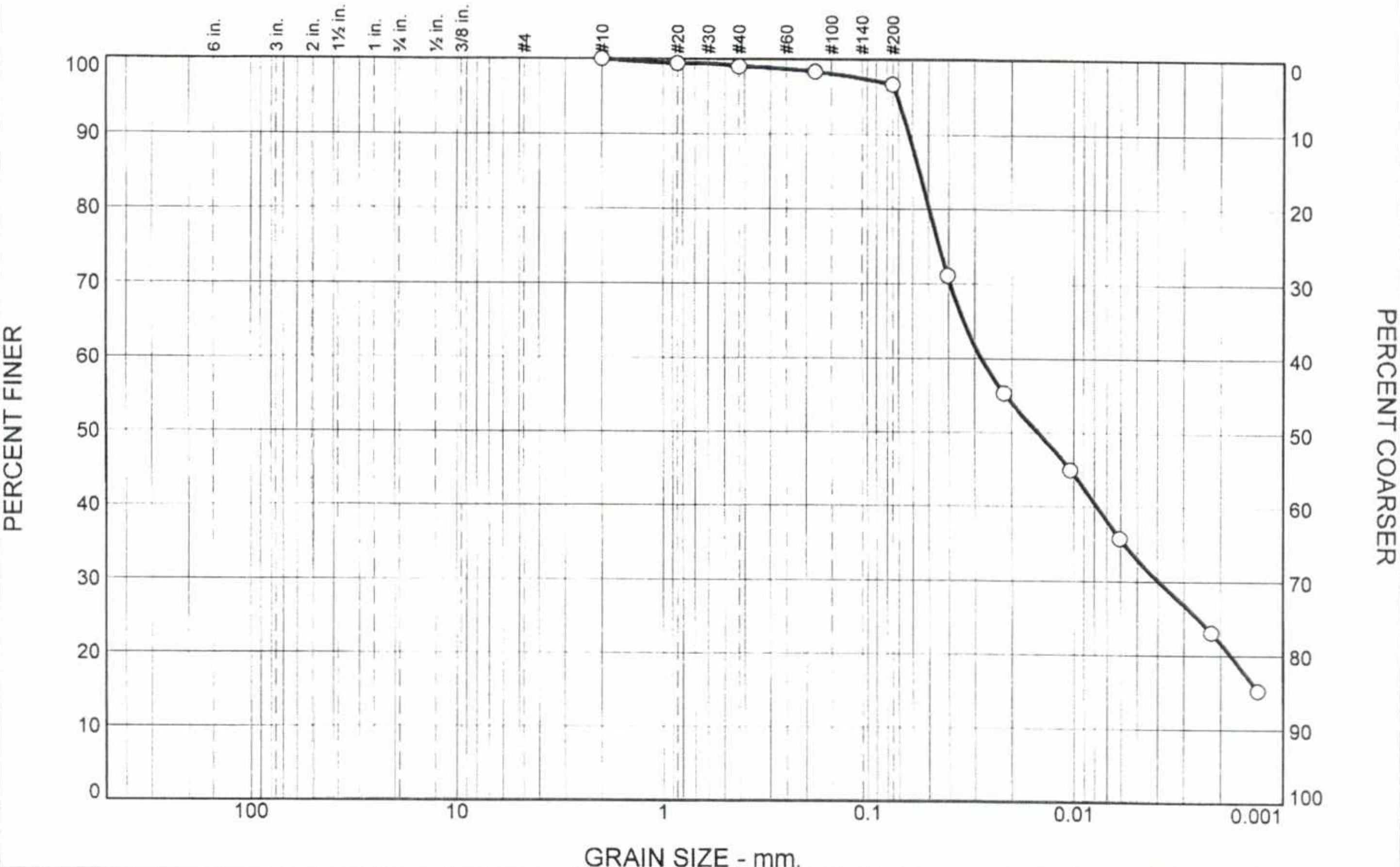
Travis Goracke, P.E.
Geotechnical Engineer

TG/ba N:\TYPING\GEOTECH\550852\Additional Info\Phase V Additional Info Letter.docx

Enclosures

Tetra Tech
P.O. Box 30615, Billings, MT 59107
618 South 25th Street, Billings, MT 59101
Tel 406.248.9161 **Fax** 406.248.9282 www.tetratech.com

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	1.0	2.3	63.8	32.9

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#10	100.0		
#20	99.4		
#40	99.0		
#80	98.3		
#200	96.7		

* (no specification provided)

Material Description

Lean Clay

Atterberg Limits

PL= 19 LL= 43 PI= 24

Coefficients

D_{90}= 0.0620 D_{85}= 0.0553 D_{60}= 0.0279
D_{50}= 0.0148 D_{30}= 0.0039 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-7-6(25)

Remarks

Source of Sample: DH-1 **Depth:** 15.0'-15.9'

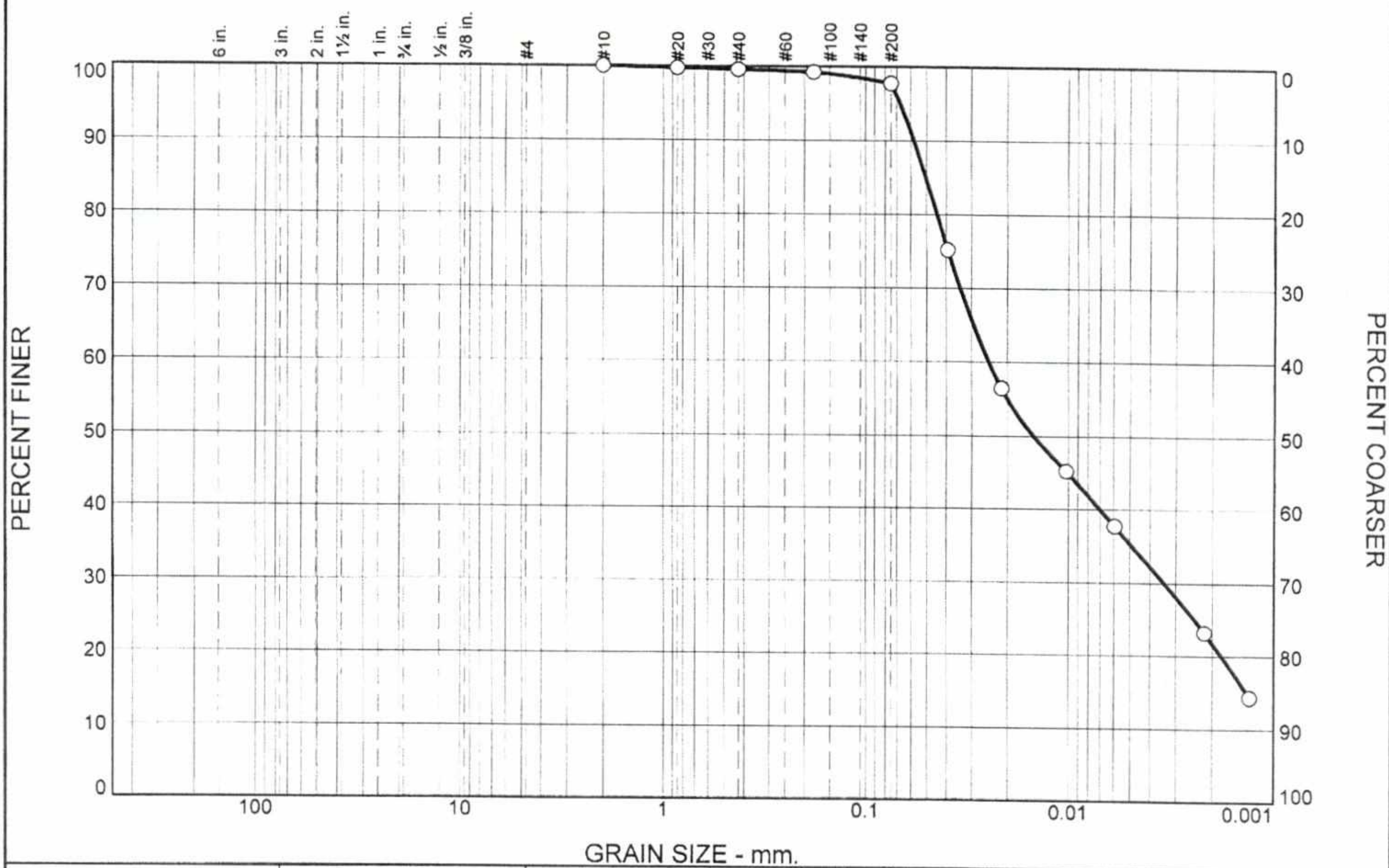
Date:

Tetra Tech, Inc.

Billings, MT

Client: Great West Engineering
Project: Billings Landfill Phase V Expansion
Project No: 114-550852 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.4	1.9	62.3	35.4

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#10	100.0		
#20	99.8		
#40	99.6		
#80	99.2		
#200	97.7		

* (no specification provided)

Material Description

Silt

Atterberg Limits

PL= 28 LL= 44 PI= 16

Coefficients

D_{90}= 0.0576 D_{85}= 0.0504 D_{60}= 0.0247
D_{50}= 0.0148 D_{30}= 0.0034 D_{15}= 0.0014
D_{10}= C_u= C_c=

Classification

USCS= ML AASHTO= A-7-6(19)

Remarks

Source of Sample: DH-1 **Depth:** 25.0'-25.7'

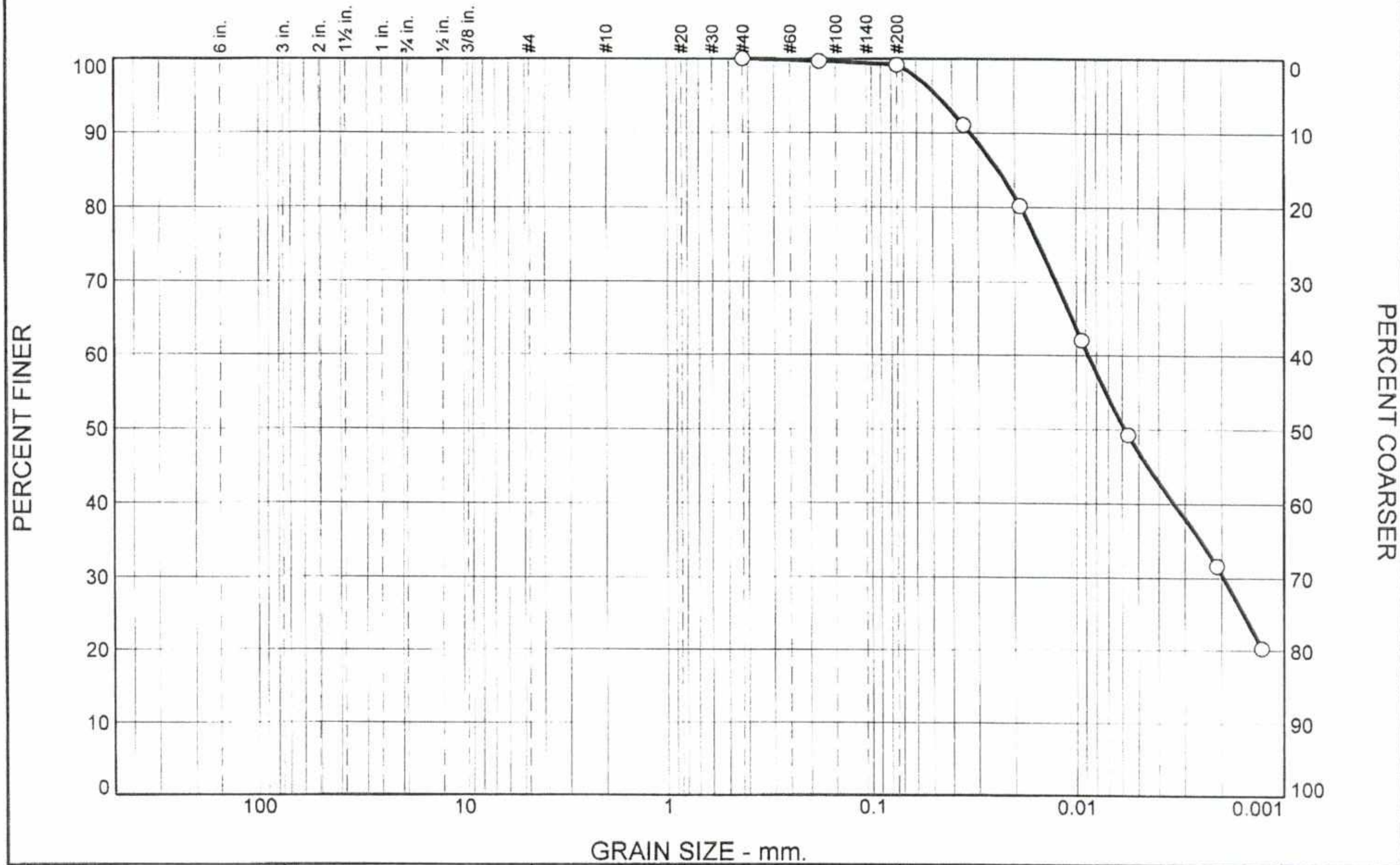
Date:

Tetra Tech, Inc.

Billings, MT

Client: Great West Engineering
Project: Billings Landfill Phase V Expansion
Project No: 114-550852 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.0	0.8	52.2	47.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#40	100.0		
#80	99.7		
#200	99.2		

* (no specification provided)

Material Description

Fat Clay

Atterberg Limits

PL= 19 LL= 59 PI= 40

Coefficients

D_{90}= 0.0326 D_{85}= 0.0239 D_{60}= 0.0088
D_{50}= 0.0058 D_{30}= 0.0019 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CH AASHTO= A-7-6(44)

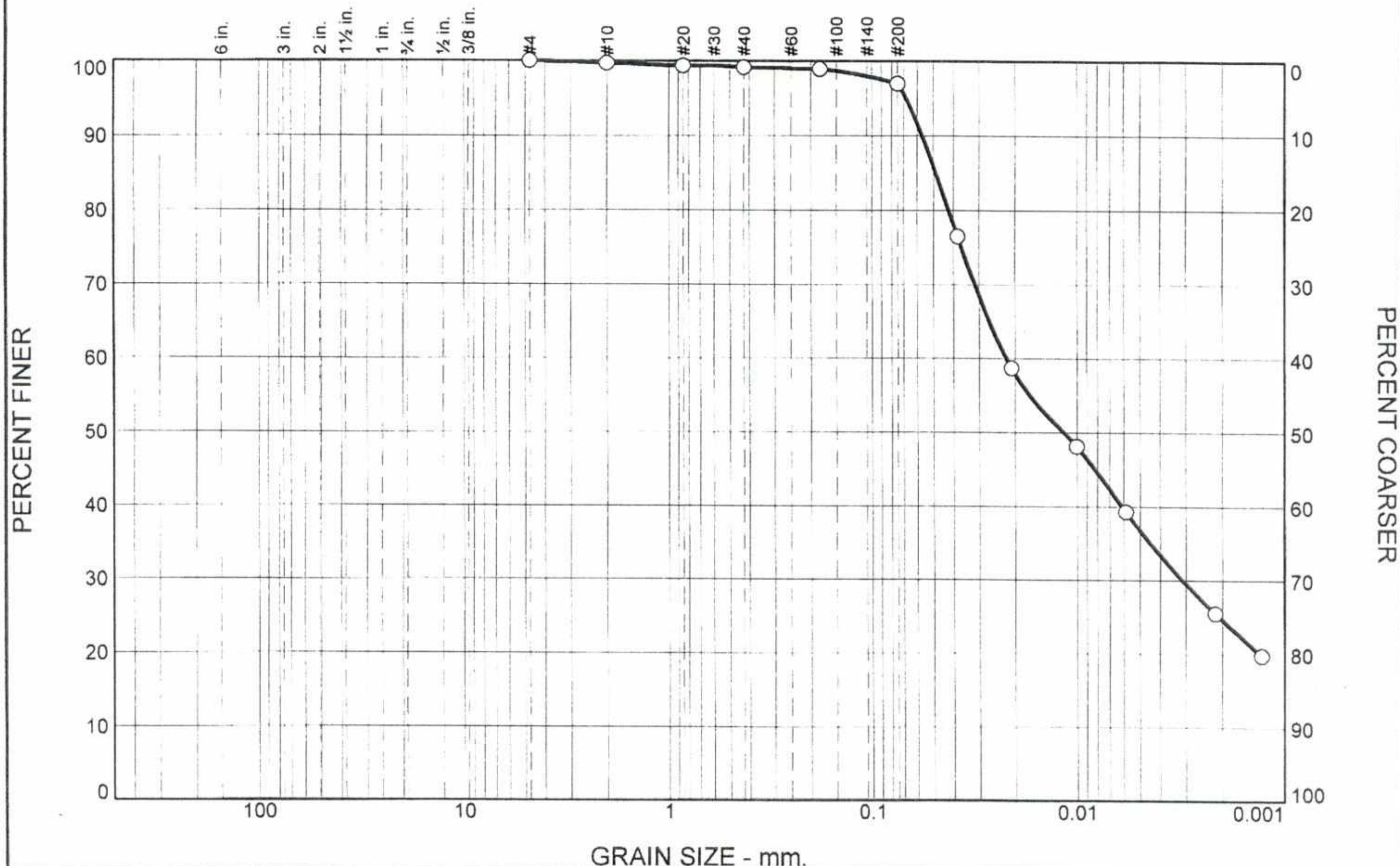
Remarks

Source of Sample: DH-1 **Depth:** 35.0'-35.5'

Date:

Tetra Tech, Inc. **Billings, MT**	**Client:** Great West Engineering **Project:** Billings Landfill Phase V Expansion **Project No:** 114-550852 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.3	0.6	2.1	60.3	36.7

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	99.7		
#20	99.4		
#40	99.1		
#80	98.9		
#200	97.0		

* (no specification provided)

Material Description

Lean Clay

Atterberg Limits

PL= 19 LL= 43 PI= 24

Coefficients

D_{90}= 0.0567 D_{85}= 0.0486 D_{60}= 0.0221

D_{50}= 0.0116 D_{30}= 0.0031 D_{15}=

D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-7-6(25)

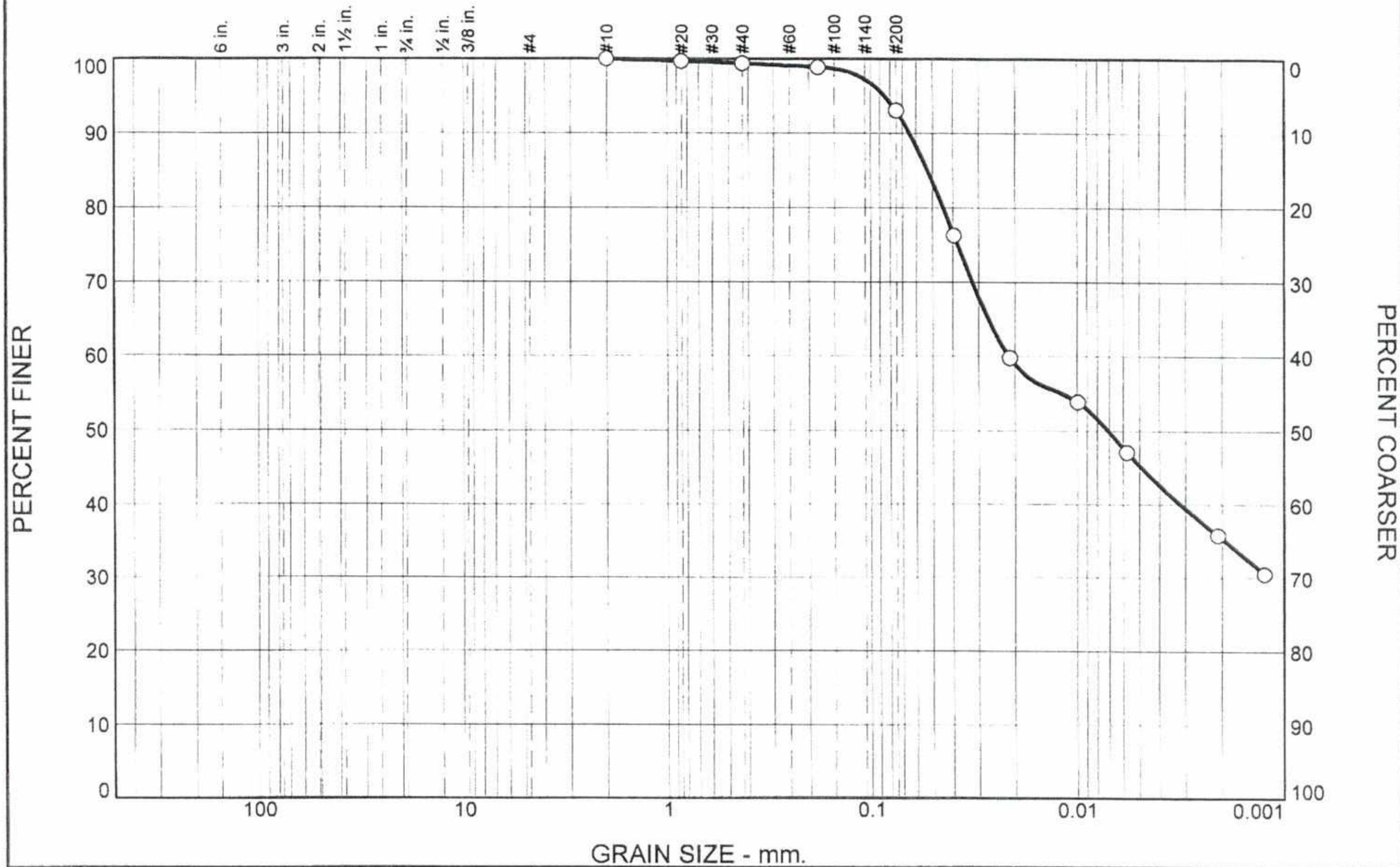
Remarks

Source of Sample: DH-2 **Depth:** 20.0'-20.4'

Date:

Tetra Tech, Inc.	**Client:** Great West Engineering
	Project: Billings Landfill Phase V Expansion
Billings, MT	**Project No:** 114-550852 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.6	6.3	47.8	45.3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#10	100.0		
#20	99.7		
#40	99.4		
#80	98.9		
#200	93.1		

* (no specification provided)

Material Description

Lean Clay

Atterberg Limits

PL= 18 LL= 45 PI= 27

Coefficients

D_{90}= 0.0643 D_{85}= 0.0528 D_{60}= 0.0215
D_{50}= 0.0071 D_{30}= D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-7-6(26)

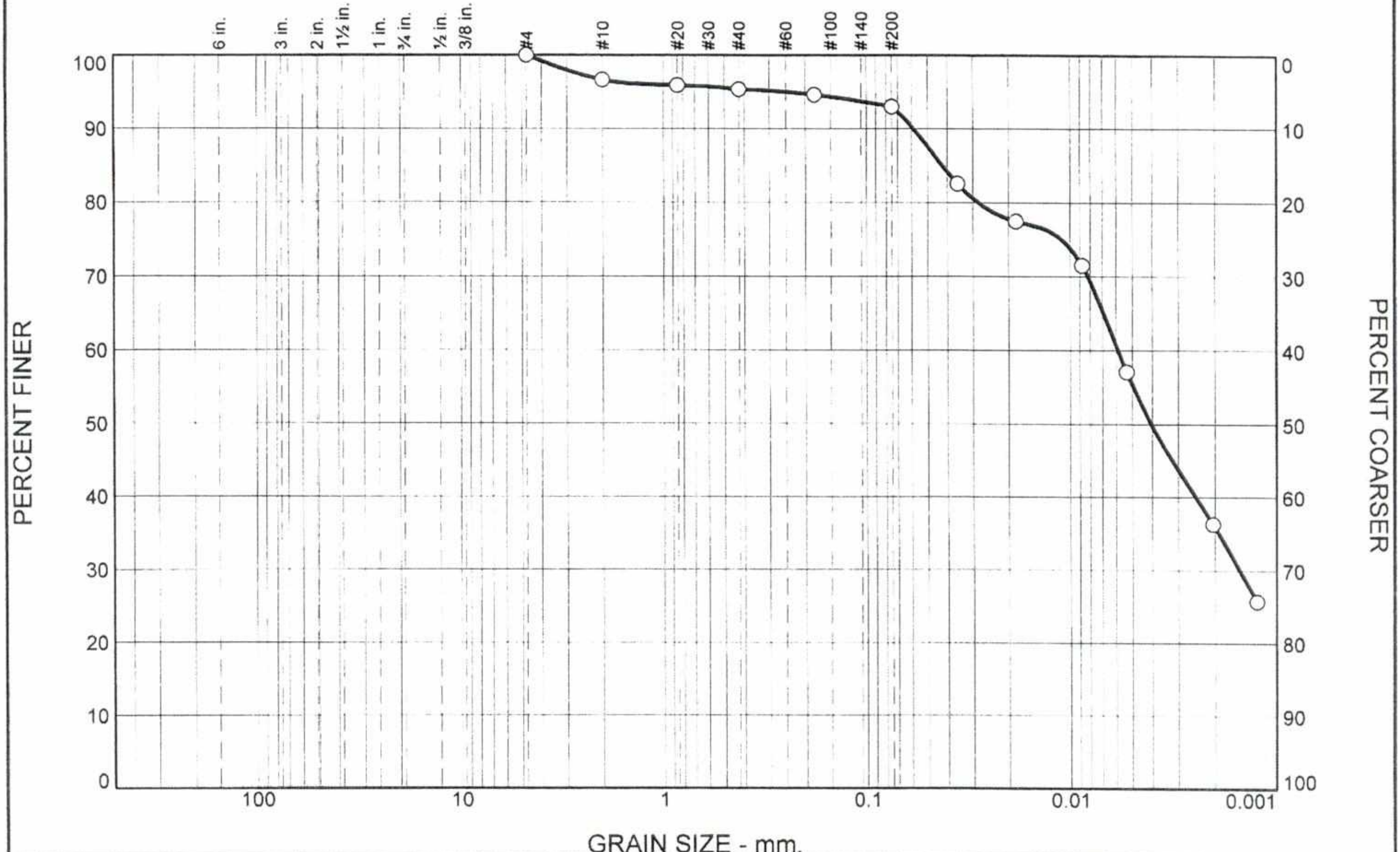
Remarks

Source of Sample: DH-2 **Depth:** 35.0'-35.4'

Date:

Tetra Tech, Inc. **Billings, MT**	**Client:** Great West Engineering **Project:** Billings Landfill Phase V Expansion **Project No:** 114-550852 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	3.4	1.3	2.3	37.7	55.3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	96.6		
#20	95.9		
#40	95.3		
#80	94.6		
#200	93.0		

* (no specification provided)

Material Description

Fat Clay

Atterberg Limits

PL= 20 LL= 67 PI= 47

Coefficients

D_{90}= 0.0587 D_{85}= 0.0424 D_{60}= 0.0059
D_{50}= 0.0040 D_{30}= 0.0015 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CH AASHTO= A-7-6(48)

Remarks

Source of Sample: DH-1 **Depth:** 45.0'-45.4'

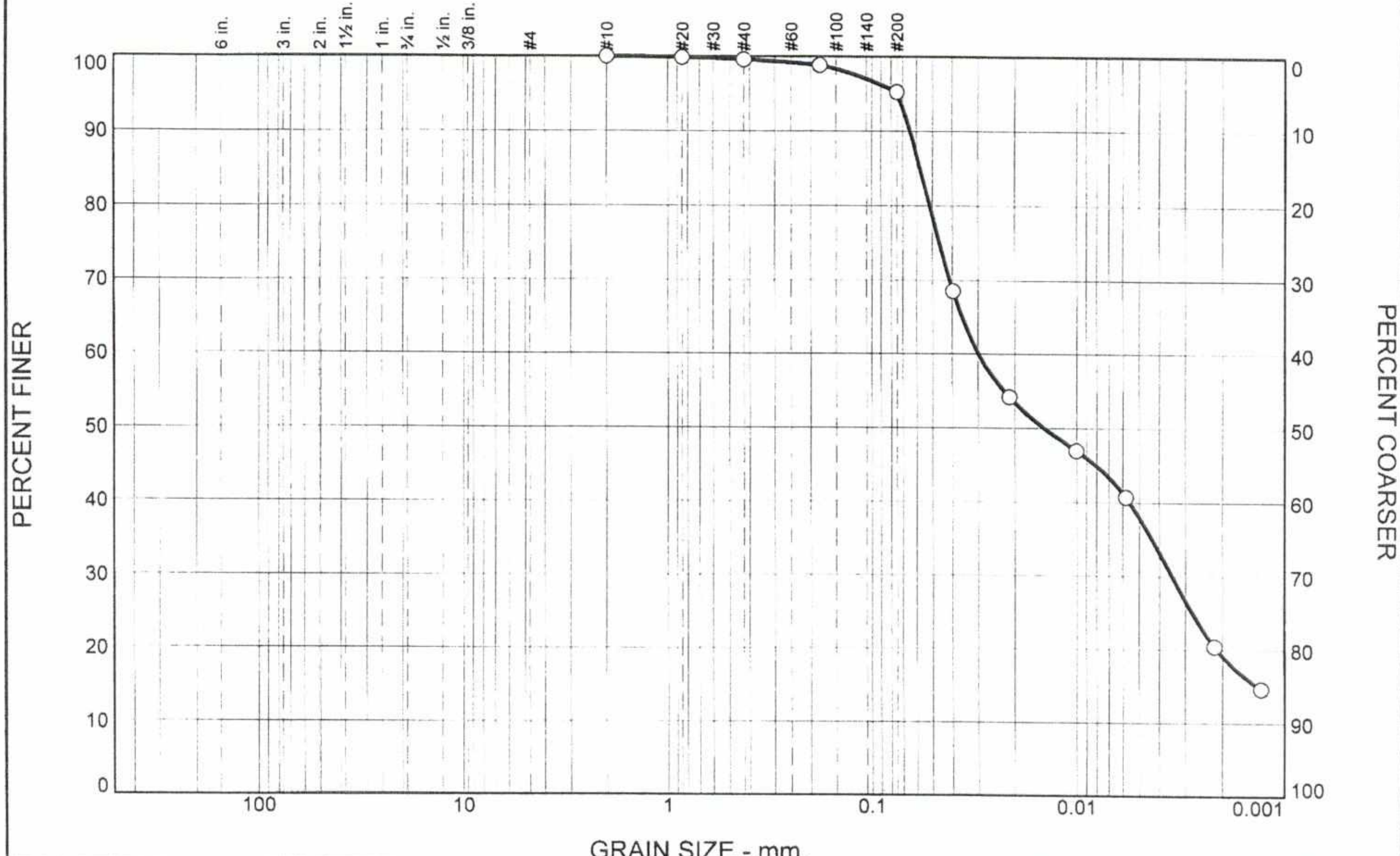
Date:

Tetra Tech, Inc.

Billings, MT

Client: Great West Engineering
Project: Billings Landfill Phase V Expansion
Project No: 114-550852 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.4	4.3	57.3	38.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#10	100.0		
#20	99.9		
#40	99.6		
#80	98.9		
#200	95.3		

* (no specification provided)

Material Description

Lean Clay

Atterberg Limits

PL= 19 LL= 42 PI= 23

Coefficients

D_{90}= 0.0645 D_{85}= 0.0574 D_{60}= 0.0298
D_{50}= 0.0143 D_{30}= 0.0035 D_{15}= 0.0013
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-7-6(23)

Remarks

Source of Sample: DH-3 **Depth:** 55.0'-60.0'

Date:

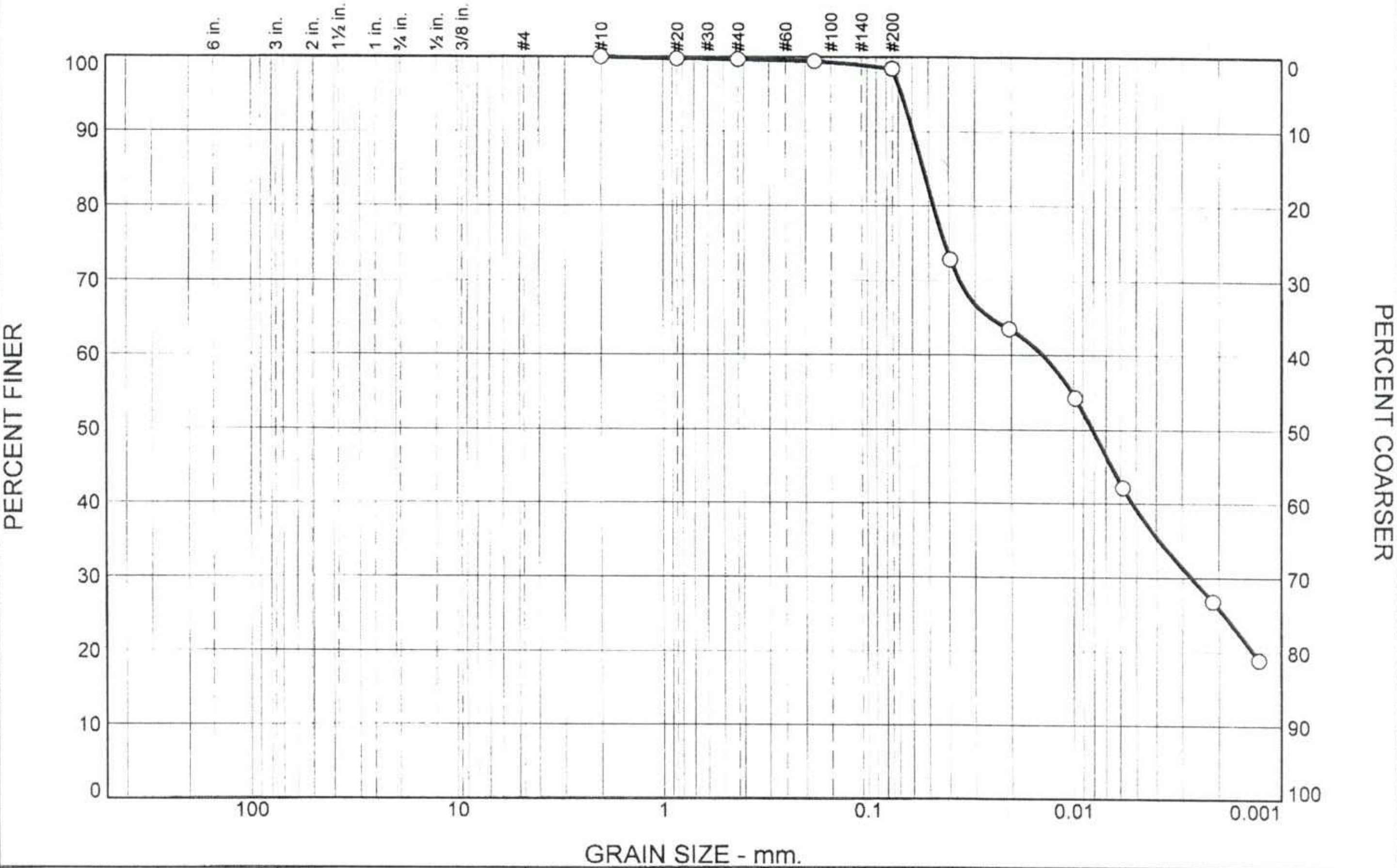
Tetra Tech, Inc.

Billings, MT

Client: Great West Engineering
Project: Billings Landfill Phase V Expansion

Project No: 114-550852 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.3	1.3	59.2	39.2

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#10	100.0		
#20	99.8		
#40	99.7		
#80	99.4		
#200	98.4		

* (no specification provided)

Material Description

Lean Clay

Atterberg Limits

PL= 20 LL= 48 PI= 28

Coefficients

D_{90}= 0.0594 D_{85}= 0.0530 D_{60}= 0.0140
D_{50}= 0.0081 D_{30}= 0.0027 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-7-6(30)

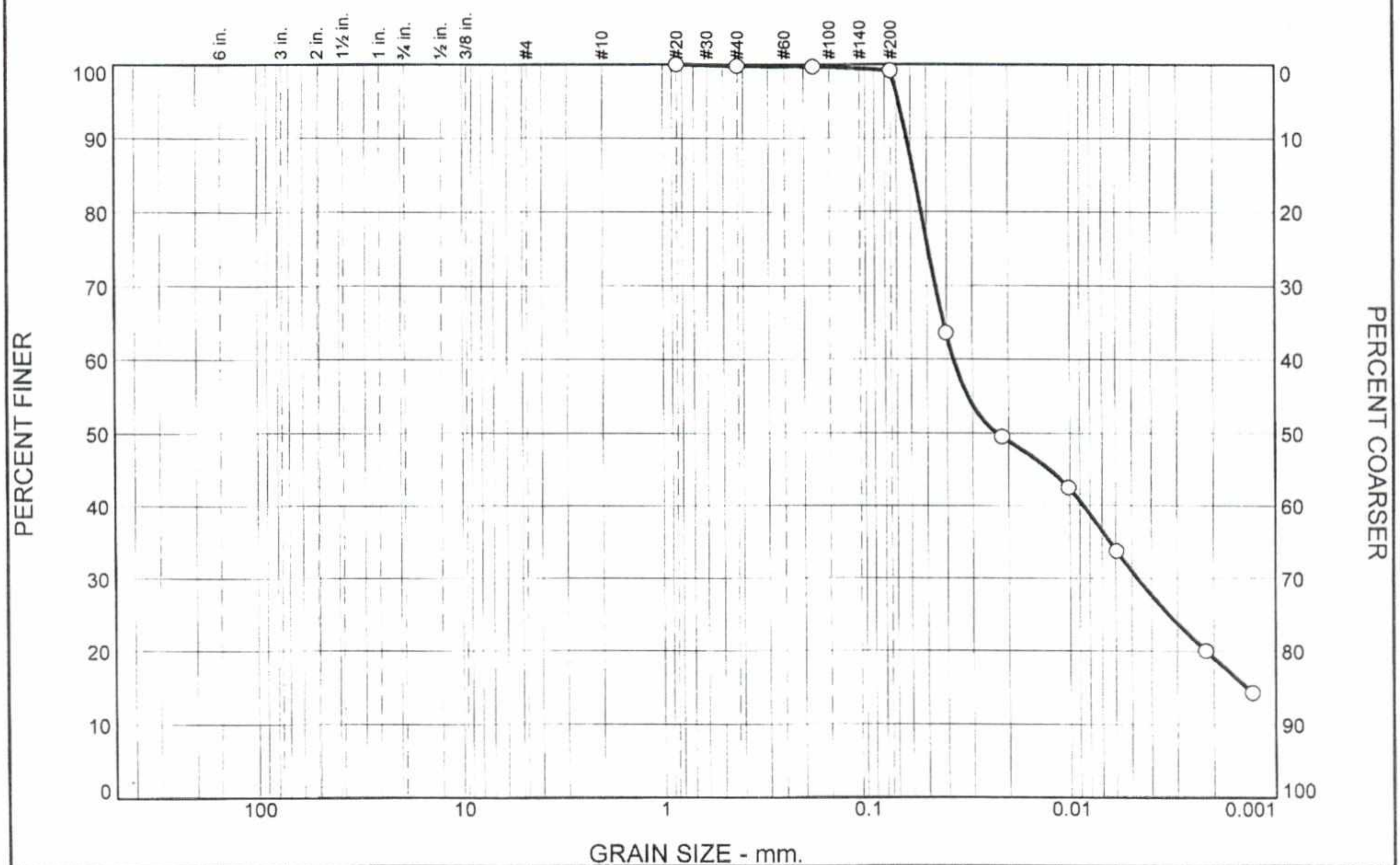
Remarks

Source of Sample: DH-3 **Depth:** 70.0'-75.0'

Date:

Tetra Tech, Inc.	**Client:** Great West Engineering
	Project: Billings Landfill Phase V Expansion
Billings, MT	**Project No:** 114-550852 **Figure**

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.2	0.6	68.2	31.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#20	100.0		
#40	99.8		
#80	99.7		
#200	99.2		

* (no specification provided)

Material Description

Fat Clay

Atterberg Limits

PL= 22 LL= 55 PI= 33

Coefficients

D_{90}= 0.0624 D_{85}= 0.0575 D_{60}= 0.0371
D_{50}= 0.0227 D_{30}= 0.0047 D_{15}= 0.0014
D_{10}= C_u= C_c=

Classification

USCS= CH AASHTO= A-7-6(37)

Remarks

Source of Sample: DH-3 **Depth:** 85.0'-90.0'

Date:

Tetra Tech, Inc.

Billings, MT

Client: Great West Engineering
Project: Billings Landfill Phase V Expansion

Project No: 114-550852 **Figure**

90-544

REPORT
OF
GEOTECHNICAL INVESTIGATION

DAMSCHEN AND ASSOCIATES
P O BOX 4817
HELENA, MT 59604

BILLINGS LANDFILL
FIELD EXPLORATION SERVICES
CHEN-NORTHERN PROJECT NO. 90-544

PREPARED
BY
CHEN-NORTHERN, INC.
CONSULTING GEOTECHNICAL ENGINEERS
BILLINGS, MONTANA

AUGUST, 1990

August 14, 1990

Damschen and Associates
P O Box 4817
Helena, MT 59604

SUBJECT: Billings Landfill
Field Exploration Services

ATTENTION: Mr. Barry Damschen

Gentlemen:

At your request and in accordance with our agreement dated May 16, 1990 we have completed Tasks II and III of the proposed scope of services for the subject project. We have discussed our findings and recommendations with you as the work progressed.

The field exploration was conducted on May 9 and 10, 1990. Three borings were drilled and ten test pits excavated during the field exploration to observe subsoil and groundwater conditions near the central portion of the landfill site. The three exploration borings and two of the ten test pits were completed as temporary geotechnical observation holes for monitoring seepage levels in the claystone. Locations of the exploratory borings and test pits were approximated by you, referenced to recent aerial photography of the site; elevations were also provided by you. The approximate boring and test pit locations are shown on the enclosed site plan.

Subsoils at the site consist primarily of lean clay underlain by claystone and bentonite. The clay soil is typically firm to stiff and has low to medium plasticity. The claystone and bentonite are moderately hard to hard rock with high plasticity. Joint discontinuities are prevalent in the claystone and appear to be a primary seepage path in the area. During the field investigation numerous seeps were encountered in the test pits originating from joint surfaces exposed in the pit walls.

Enclosed are drill logs for each test pit and exploration boring. Test results from laboratory analysis of soil samples, joint orientations and groundwater levels are presented on the logs. Results of water quality tests were previously submitted in our technical report dated June 28, 1990. The invoice for field investigation and laboratory services is attached.

If you have any questions or if we can be of further service, please contact us.

Respectfully submitted

CHEN-NORTHERN, INC

David M. Hummel, Jr., P.E.

Richard P. Dombrouski

DMH(RPD)rl
Enclosures

Chen Northern, Inc.

A member of the HIH group of companies

LOG OF EXPLORATION BORING

PROJECT: BILLINGS LANDFILL

JOB NO.: 90-544

DRILL TYPE: SOIL MOBIL B 53, HOLLOWSTEM AUGERS

ROCK

DRILLED BY: BEN KRUEGER

LOGGED BY: R. DOMBROUSKI

REMARKS:

HOLE NO. DH-90-1

SHEET 1 OF 1

LOCATION: Refer to Site Plan

ELEVATION: TOP OF HOLE 3425.1

GROUNDWATER

DATE: HOLE STARTED 5/9/90

COMPLETED 5/9/90

DEPTH (Feet)	LEGEND	CLASSIFICATION AND DESCRIPTION	SAMPLE SYMBOL	S.P.T. (N) (BLOWS/FT.)	MOISTURE CONTENT (%)	IN-PLACE DRY DENSITY (pcf)	L.L. %	P.I. %	GRAVEL %	SAND %	SILT %	CLAY %
0.0		CLAYSTONE; gray, moderately hard rock, laminated, weathered, salts, jointed	LSS	50/0.4	16							
			LSS	50/0.4	17							
10												
13.5		BENTONITE; white-gray, soft to moderately hard rock, high plasticity, moist	LSS	50/0.3	26							
			LSS	50/0.0	-							
20.0		CLAYSTONE and SHALE; gray, hard rock, fissile, slightly weathered	LSS	50/0.0	-							
			LSS	50/0.0	-							
28.5		BOTTOM OF HOLE										

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LOG OF EXPLORATION BORING

PROJECT: BILLINGS LANDFILL
JOB NO.: 90-544
DRILL TYPE: SOIL MOBIL B 53, HOLLOWSTEM AUGERS
ROCK
DRILLED BY: BEN KRUEGER
LOGGED BY: R. DOMBROUSKI
REMARKS:

HOLE NO. DH-90-2
SHEET 1 OF 2
LOCATION: Refer to Site Plan
ELEVATION: TOP OF HOLE 3454.6
GROUNDWATER
DATE: HOLE STARTED 5/9/90
COMPLETED 5/9/90

DEPTH (Feet)	LEGEND	CLASSIFICATION AND DESCRIPTION	SAMPLE SYMBOL	S.P.T. (N) (BLOWS/FT.)	MOISTURE CONTENT (%)	IN-PLACE DRY DENSITY (pcf)	L.L. %	P.I. %	GRAVEL %	SAND %	SILT %	CLAY %
0.0		Lean CLAY; stiff, moist, low plasticity, scattered claystone gravels, brown										
4.0			LSS	49	14							
10			LSS	50/0.4	12							
			LSS	87/0.9	11							
20		CLAYSTONE; dark gray, soft to moderately hard rock, laminated, salts, jointed, becoming sandy below 8.5 feet, color change to brown at 8.0 feet, methane pocket from 33.5 to 38.5 feet	LSS	50/0.5	10							
			LSS	50/0.3	16							
30			LSS	50/0.4	14							
			LSS	50/0.2	13							
38.5 40		BENTONITE; white-gray, soft to moderately hard rock, high plasticity, moist	LSS	50/0.2	24							

continued . . .

LOG OF EXPLORATION BORING

JOB NO. 90-544 HOLE NO. DH-90-2 SHEET 2 OF 2

DEPTH (Feet)	LEGEND	CLASSIFICATION AND DESCRIPTION	SAMPLE SYMBOL	S P T (N) (BLOWS FT.)	MOISTURE CONTENT (%)	IN-PLACE DRY DENSITY (pcf)	L L %	P I %	GRAVEL %	SAND %	SILT %	CLAY %
40		continued . . .										
40.7		BENTONITE; white-gray, soft to moderately hard rock, high plasticity, moist										
		CLAYSTONE	LSS	25/0.0	-							
43.5		BOTTOM OF HOLE										

NET 122C

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LOG OF EXPLORATION BORING

PROJECT: BILLINGS LANDFILL
JOB NO.: 90-544
DRILL TYPE: SOIL MOBIL B 53, HOLLOWSTEIN AUGERS
ROCK
DRILLED BY: BEN KRUEGER
LOGGED BY: R. DOMBROUSKI
REMARKS:

HOLE NO. DH-90-3
SHEET 1 OF 2
LOCATION: Refer to Site Plan
ELEVATION: TOP OF HOLE 3462.4
GROUNDWATER
DATE: HOLE STARTED 5/10/90
COMPLETED 5/10/90

DEPTH (Feet): 0.0 – 40

CLASSIFICATION AND DESCRIPTION: CLAYSTONE; dark gray, moderately hard rock, laminated, high salt content, jointed, becoming hard below 15 feet

SAMPLE SYMBOL	S.P.T. (N) (BLOWS/FT.)	MOISTURE CONTENT (%)	IN-PLACE DRY DENSITY (pcf)	L.L. %	P.I. %	GRAVEL %	SAND %	SILT %	CLAY %
LSS	87	11							
LSS	82	10							
LSS	50/0.3	5							
LSS	50/0.3	6							
LSS	50/0.4	5							
LSS	50/0.4	13							
LSS	50/0.4	-							
LSS	50/0.2	-							

continued . . .

LOG OF EXPLORATION BORING

JOB NO. 90-544 HOLE NO. DH-90-3 SHEET 2 OF 2

DEPTH (Feet)	LEGEND	CLASSIFICATION AND DESCRIPTION	SAMPLE SYMBOL	S P T (N) (BLOWS/FT.)	MOISTURE CONTENT (%)	IN-PLACE DRY DENSITY (pcf)	L L %	P I %	GRAVEL %	SAND %	SILT %	CLAY %
40		CLAYSTONE; dark gray, moderately hard rock, laminated, high salt content, jointed, becoming hard below 15 feet										
42.6		BENTONITE light gray, very soft rock, high plasticity, moist	STS	25/0.0	-	84	167	126	0	4	-96-	
44.6		BOTTOM OF HOLE	LSS			Coefficient of Permeability: k = 4×10^{-9} cm/sec						

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LOG OF EXPLORATION BORING

PROJECT: BILLINGS LANDFILL
JOB NO.: 90-544
DRILL TYPE: SOIL BACKHOE, JD610
ROCK
DRILLED BY: CITY OF BILLINGS
LOGGED BY: R. DOMBROUSKI
REMARKS:

HOLE NO. TP-1
SHEET 1 OF 1
LOCATION: Refer to Site Plan
ELEVATION: TOP OF HOLE 3433.5
GROUNDWATER
DATE: HOLE STARTED 5/9/90
COMPLETED 5/9/90

DEPTH (Feet)	LEGEND	CLASSIFICATION AND DESCRIPTION	SAMPLE SYMBOL	S.P.T. (N) (BLOWS/FT.)	MOISTURE CONTENT (%)	IN-PLACE DRY DENSITY (pcf)	L.L. %	P.I. %	GRAVEL %	SAND %	SILT %	CLAY %
0.0–6.4 (0.0, 0.5, 5, 6.0, 6.3, 6.4)		CLAYSTONE; dark gray to brown, soft to moderately hard rock, very weathered, weakly cemented, thinly bedded, jointed, thin bentonite seam from 6.0 to 6.3 feet, low to moderate water inflow from joints	SACK	-	41		90	57	0	5	-95-	
		BOTTOM OF HOLE										

Joint Orientations

1. N 64° W, 81° NE
2. N 69° W, 81° NE
3. N 16° W, 79° SE

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LOG OF EXPLORATION BORING

PROJECT: BILLINGS LANDFILL
JOB NO. 90-544
DRILL TYPE: SOIL BACKHOE, JD610
ROCK
DRILLED BY: CITY OF BILLINGS
LOGGED BY: R. DOMBROUSKI
REMARKS:

HOLE NO. TP-2
SHEET 1 OF 1
LOCATION: Refer to Site Plan
ELEVATION: TOP OF HOLE 3473.0
GROUNDWATER
DATE: HOLE STARTED 5/9/90
COMPLETED 5/9/90

DEPTH (Feet)	LEGEND	CLASSIFICATION AND DESCRIPTION	SAMPLE SYMBOL	S.P.T. (N) (BLOWS/FT.)	MOISTURE CONTENT (%)	IN-PLACE DRY DENSITY (pcf)	L.L. %	P.I. %	GRAVEL %	SAND %	SILT %	CLAY %
0.0–0.5		TOPSOIL with organic material										
0.5–4.0		Poorly Graded GRAVEL with Sand; very dense, slightly moist, nonplastic, scattered cobbles, estimate 8" maximum size, subrouded to rounded										
4.0–5.0		Lean CLAY; stiff, moist, low to medium plasticity, dark brown										
5.0–12.0		CLAYSTONE; dark gray, soft to moderately hard rock, slightly weathered, jointed, salts	L.SACK		12							
			L.SACK		11							
12.0		BOTTOM OF HOLE										

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LOG OF EXPLORATION BORING

PROJECT: BILLINGS LANDFILL
JOB NO.: 90-544
DRILL TYPE: SOIL BACKHOE, JD610
ROCK
DRILLED BY: CITY OF BILLINGS
LOGGED BY: R. DOMBROUSKI
REMARKS:

HOLE NO. TP-3
SHEET 1 OF 1
LOCATION: Refer to Site Plan
ELEVATION: TOP OF HOLE 3452.3
GROUNDWATER
DATE: HOLE STARTED 5/9/90
COMPLETED 5/9/90

DEPTH (Feet)	LEGEND	CLASSIFICATION AND DESCRIPTION	SAMPLE SYMBOL	S.P.T. (N) (BLOWS/FT.)	MOISTURE CONTENT (%)	IN-PLACE DRY DENSITY (pcf)	L.L. %	P.I. %	GRAVEL %	SAND %	SILT %	CLAY %
0.0		TOPSOIL with organic material										
0.2		Lean CLAY with Sand; firm to stiff, very moist, medium plasticity, claystone fragments, brown										
2.9												
5		CLAYSTONE; dark gray, moderately hard rock, weakly cemented, thinly laminated, jointed, water inflow fromjoint at 8.6 feet Joint Orientation N 25° E, 90°	SACK	-	11							
9.7		BOTTOM OF HOLE										

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LOG OF EXPLORATION BORING

PROJECT: BILLINGS LANDFILL

JOB NO.: 90-544

DRILL TYPE: SOIL BACKHOE, JD610

ROCK

DRILLED BY: CITY OF BILLINGS

LOGGED BY: R. DOMBROUSKI

REMARKS:

HOLE NO. TP-4

SHEET 1 OF 1

LOCATION: Refer to Site Plan

ELEVATION: TOP OF HOLE 3404.8

GROUNDWATER

DATE: HOLE STARTED 5/9/90

COMPLETED 5/9/90

DEPTH (Feet)	LEGEND	CLASSIFICATION AND DESCRIPTION	SAMPLE SYMBOL	S.P.T. (N) (BLOWS/FT.)	MOISTURE CONTENT (%)	IN-PLACE DRY DENSITY (pcf)	L.L. %	P.I. %	GRAVEL %	SAND %	SILT %	CLAY %
0.0 – 3.0		Lean CLAY; firm to stiff, medium, moist, brown										
3.0 – 12.0		CLAYSTONE; dark gray, soft rock, weathered, moist, laminated, jointed										
12.0		BOTTOM OF HOLE										

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LOG OF EXPLORATION BORING

PROJECT: BILLINGS LANDFILL

JOB NO.: 90-544

DRILL TYPE: SOIL BACKHOE, JD610

ROCK

DRILLED BY: CITY OF BILLINGS

LOGGED BY: R. DOMBROUSKI

REMARKS:

HOLE NO. TP-5

SHEET 1 OF 1

LOCATION: Refer to Site Plan

ELEVATION: TOP OF HOLE 3398.2

GROUNDWATER

DATE: HOLE STARTED 5/9/90

COMPLETED 5/9/90

DEPTH (Feet)	LEGEND	CLASSIFICATION AND DESCRIPTION	SAMPLE SYMBOL	S.P.T. (N) (BLOWS/FT.)	MOISTURE CONTENT (%)	IN-PLACE DRY DENSITY (pcf)	L.L. %	P.I. %	GRAVEL %	SAND %	SILT %	CLAY %
0.0 – 2.5		Fat CLAY; stiff, very moist, high plasticity, salts, brown	SACK		38							
2.5 – 13.0		CLAYSTONE; dark gray, soft to moderately hard rock, moist, laminated, weakly cemented, jointed Joint Orientation N 22° E, 77° NW	SACK		14							
13.0		BOTTOM OF HOLE										

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LOG OF EXPLORATION BORING

PROJECT: BILLINGS LANDFILL

JOB NO.: 90-544

DRILL TYPE: SOIL BACKHOE, JD610

ROCK

DRILLED BY: CITY OF BILLINGS

LOGGED BY: R. DOMBROUSKI

REMARKS:

HOLE NO. TP-6

SHEET 1 OF 1

LOCATION: Refer to Site Plan

ELEVATION: TOP OF HOLE 3386.4

GROUNDWATER

DATE: HOLE STARTED 5/9/90

COMPLETED 5/9/90

DEPTH (Feet)	LEGEND	CLASSIFICATION AND DESCRIPTION	SAMPLE SYMBOL	S.P.T. (N) (BLOWS/FT.)	MOISTURE CONTENT (%)	IN-PLACE DRY DENSITY (pcf)	L.L %	P.I. %	GRAVEL %	SAND %	SILT %	CLAY %
0.0–0.3		TOPSOIL with organic material										
0.3–4.5		FILL; Lean Clay; firm, moist, medium plasticity, wood debris, garbage and refuse										
4.5–9.8		CLAYSTONE; gray to cream, soft rock, laminated, slightly moist, bentonite seam from 6.5 to 7.3 feet	L. SACK		12							
			L. SACK		11							
9.8		BOTTOM OF HOLE										

(Rev. 1/89) CNI-122B

Chen Northern, Inc.

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LOG OF EXPLORATION BORING

PROJECT: BILLINGS LANDFILL

JOB NO.: 90-544

DRILL TYPE: SOIL MOBIL B 53, HOLLOWSTEIN AUGERS

ROCK

DRILLED BY: BEN KRUEGER

LOGGED BY: R. DOMBROUSKI

REMARKS:

HOLE NO. TP-7

SHEET | OF |

LOCATION: Refer to Site Plan

ELEVATION: TOP OF HOLE 3384.7

GROUNDWATER

DATE: HOLE STARTED 5/9/90

COMPLETED 5/9/90

DEPTH (Feet)	LEGEND	CLASSIFICATION AND DESCRIPTION	SAMPLE SYMBOL	S.P.T. (N) (BLOWS/FT.)	MOISTURE CONTENT (%)	IN-PLACE DRY DENSITY (pcf)	L.L. %	P.I. %	GRAVEL %	SAND %	SILT %	CLAY %
0.0		FILL; Lean Clay, very moist, firm to stiff, medium plasticity, light brown										
5.4		FILL; Garbage and Debris										
8.0		BOTTOM OF HOLE										

LOG OF EXPLORATION BORING

PROJECT: BILLINGS LANDFILL
JOB NO.: 90-544
DRILL TYPE: SOIL BACKHOE, JD610
ROCK
DRILLED BY: CITY OF BILLINGS
LOGGED BY: R. DOMBROUSKI
REMARKS:

HOLE NO. TP-8
SHEET 1 OF 1
LOCATION: Refer to Site Plan
ELEVATION: TOP OF HOLE 3408.5
GROUNDWATER
DATE: HOLE STARTED 5/9/90
COMPLETED 5/9/90

DEPTH (Feet)	LEGEND	CLASSIFICATION AND DESCRIPTION	SAMPLE SYMBOL	S.P.T. (N) (BLOWS/FT.)	MOISTURE CONTENT (%)	IN-PLACE DRY DENSITY (pcf)	L.L. %	P.I. %	GRAVEL %	SAND %	SILT %	CLAY %
0.0–0.1		TOPSOIL with organic material										
0.1–7.0		CLAYSTONE; dark gray, soft to moderately hard rock, weakly cemented, thinly laminated, jointed, low water inflow from joint at 2.2 feet Joint Orientation 1. N 23° W, 87° SE 2. N 82° E, 90° 3. N 1° W, 83° NE 4. N 70° W, 85° NE 5. N 88° W, 84° NE										
7.0–12.0		BENTONITE; gray to white, soft rock, moist, high plasticity Probable Claystone-Shale contact, Practical Bucket Refusal at 12.0 feet	SACK; L. SACK		40							
12.0		BOTTOM OF HOLE										

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LOG OF EXPLORATION BORING

PROJECT: BILLINGS LANDFILL

JOB NO.: 90-544

DRILL TYPE: SOIL BACKHOE, JD610

ROCK

DRILLED BY: CITY OF BILLINGS

LOGGED BY: R. DOMBROUSKI

REMARKS:

HOLE NO. TP-9

SHEET 1 OF 1

LOCATION: Refer to Site Plan

ELEVATION: TOP OF HOLE 3400.6

GROUNDWATER NONE ENCOUNTERED

DATE: HOLE STARTED 5/9/90

COMPLETED 5/9/90

DEPTH (Feet)	LEGEND	CLASSIFICATION AND DESCRIPTION	SAMPLE SYMBOL	S.P.T. (N) (BLOWS/FT.)	MOISTURE CONTENT (%)	IN-PLACE DRY DENSITY (pcf)	L.L. %	P.I. %	GRAVEL %	SAND %	SILT %	CLAY %
0.0 – 0.1		TOPSOIL with organic material										
0.1 – 2.0		Lean CLAY; firm, moist, medium plasticity, brown										
2.0 – 4.1		CLAYSTONE; gray, slightly moist to dry, weakly cemented, thinly laminated										
4.1 – 8.8		BENTONITE; gray to white, soft rock, very moist, high plasticity Probable Claystone-Shale contact, Practical Bucket Refusal at 8.8 feet	L SACK									
8.8		BOTTOM OF HOLE										

(Rev. 1/89) CNI-122B

Chen Northern, Inc.

A member of the HIH group of companies

LOG OF EXPLORATION BORING

PROJECT: BILLINGS LANDFILL

JOB NO.: 90-544

DRILL TYPE: SOIL

ROCK

DRILLED BY: CITY OF BILLINGS

LOGGED BY: R. DOMBROUSKI

REMARKS:

HOLE NO. TRENCH CUT TP-10

SHEET 1 OF 1

LOCATION: Refer to Site Plan

ELEVATION: TOP OF HOLE 3407.5

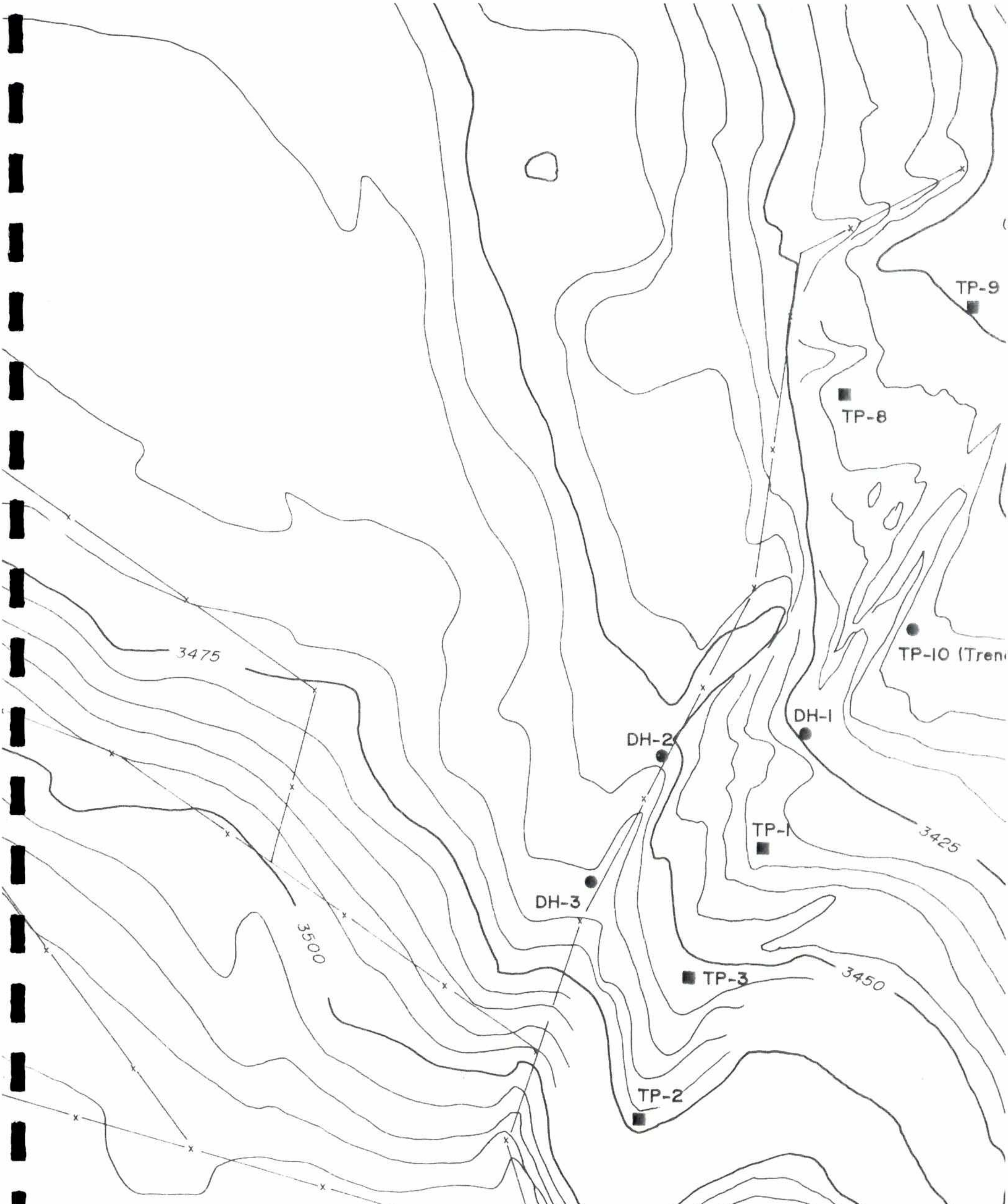
GROUNDWATER

DATE: HOLE STARTED 5/9/90

COMPLETED 5/9/90

DEPTH (Feet)	LEGEND	CLASSIFICATION AND DESCRIPTION	SAMPLE SYMBOL	S.P.T. (N) (BLOWS/FT.)	MOISTURE CONTENT (%)	IN-PLACE DRY DENSITY (pcf)	L.L. %	P.I. %	GRAVEL %	SAND %	SILT %	CLAY %
0.0–12.5		CLAYSTONE; dark gray, soft rock, thinly laminated, weakly cemented, jointed, salts, parting at 4.0 feet and 8.0 feet, moderate water inflow at 12.5 feet from joints Joint Orientation 1. N 1° E, 77° NW 2. N 74° W, 89° NE 3. N 70° W, 88° NE 4. N 70° W, 88° NE 5. N 72° W, 89° NE 6. N 16° E, 90°										
12.0		GWL (5/9/90)										
12.5		BOTTOM OF HOLE										

(Rev. 1/89) CNI-122B


TP-9
TP-8
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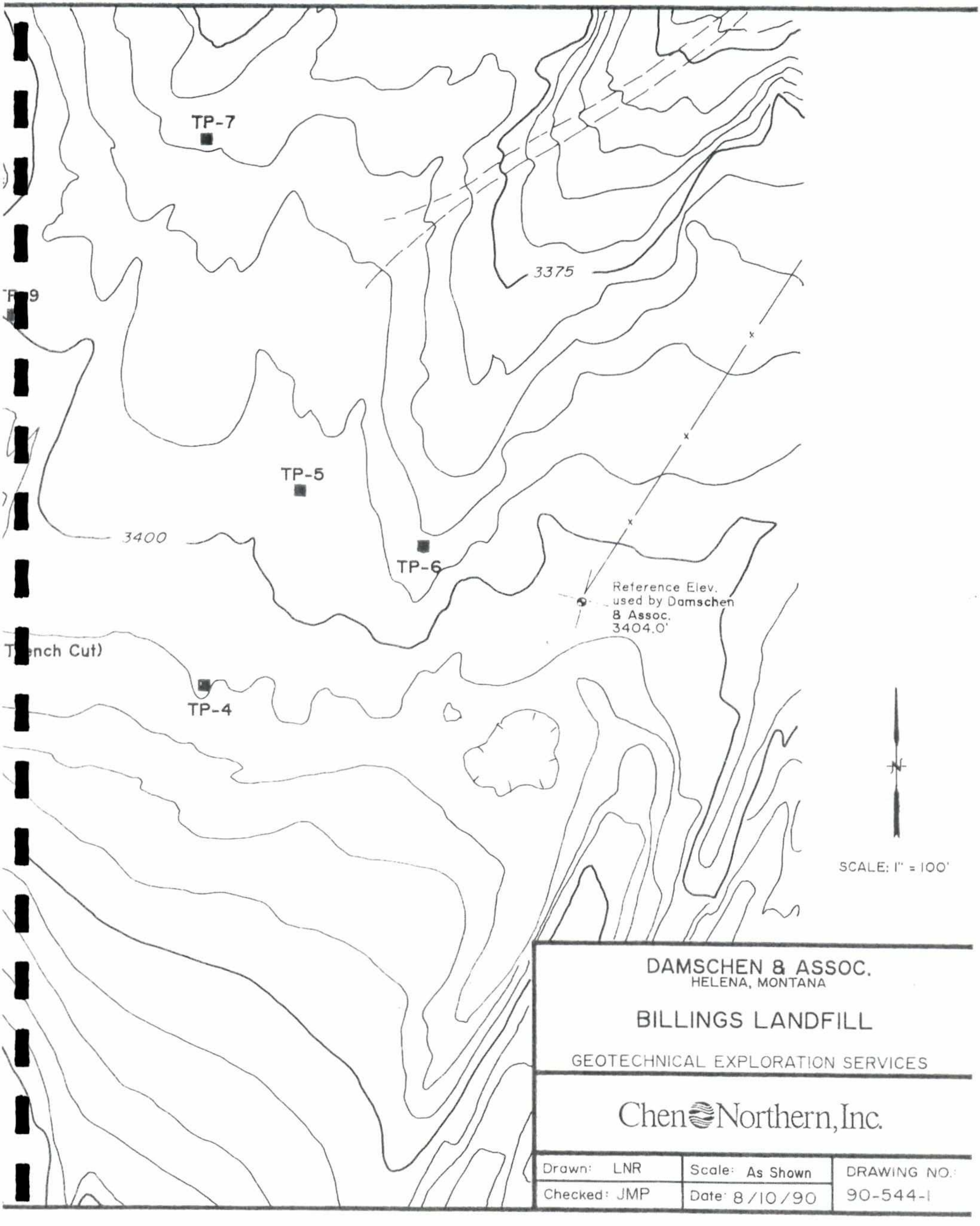
DH-1
DH-2
DH-3
TP-1
TP-3
TP-2
3475
3500
3425
3450



DAMSCHEN & ASSOC.
HELENA, MONTANA

BILLINGS LANDFILL

GEOTECHNICAL EXPLORATION SERVICES

Chen Northern, Inc.

Drawn: LNR	Scale: As Shown	DRAWING NO.:
Checked: JMP	Date: 8/10/90	90-544-1

REPORT
OF
PRELIMINARY SUBSURFACE SOILS INVESTIGATION

SANITARY LANDFILL
Billings, Montana

TO
HENNINGSON, DURHAM & RICHARDSON
CONSULTING ENGINEERS
Helena, Montana

PREPARED
BY
NORTHERN TESTING LABORATORIES, INC.
CONSULTING GEOTECHNICAL ENGINEERS
Billings, Montana

AUGUST, 1977

Ge echnical Engineering

Field and Laboratory Investigations
Engineering Analysis and Recommendations
Consultation

Great Falls Billings Montana — Boise Idaho — Gillette Wyoming

P.O. Box 30615
600 South Twenty-fifth Street
Billings, Montana 59103
(406) 248-9161

August 17, 1977

Henningson, Durham & Richardson
Consulting Engineers
2225 Eleventh Avenue
Helena, Montana 59601

ATTENTION: Mr. Barry E. Damschen

Subject: Preliminary Subsurface Soils Investigation
Billings Sanitary Landfill

Gentlemen:

In accordance with our agreement dated May 11, 1977, we have made a preliminary subsurface soils investigation at the site of the proposed Billings sanitary landfill expansion. The purpose of this investigation was to provide subsurface information for use in planning.

A preliminary scope of work was developed in the field after conversation with your personnel, which included the following:

1) Recommendations for maximum excavation and fill slopes, based on past experience with similar soil types.

2) Determine if rock excavation will be required.

3) In-place and remolded permeability tests for materials used as cover over the landfill and at the base.

Our findings are briefly summarized below and a complete summary of the field and laboratory test results and test boring logs are enclosed.

FIELD INVESTIGATIONS

Six test borings were drilled to depths varying from 17.6 to 48.9 feet. The locations and elevations of the borings were determined by your personnel.

Continuous logs of the soil conditions were recorded, standard penetration resistance and field permeability tests made, and disturbed, undisturbed and NQ core samples obtained, during the field drilling program. The core samples were taken in the bedrock near the estimated base elevation. They were classified and a rock quality designation (RQD) analysis was calculated in the field. The RQD factor, shown on the drill logs, is determined by summing the length of all pieces of sound core, 4 inches or greater in length, and dividing this length by the total length of the core run. These values provide information helpful in evaluating the subsoil permeability and in determining the depth to which the material can be excavated.

A 30-foot-length of 4-inch-diameter perforated PVC pipe was installed in Drill Hole 4 for water sampling and monitoring groundwater levels.

LABORATORY INVESTIGATIONS

Samples obtained during the field exploration were taken to the laboratory where they were carefully inspected and visually classified in accordance with the Unified Soils Classification System. Representative samples were selected for tests to determine the engineering and physical properties of the soils.

These included:	To determine:
Grain-size distribution............	size and distribution of soil particles, i.e., clay, silt, sand, gravel.
Atterberg limits..................	the consistency and "stickiness," as well as the range of moisture content within which the material is "workable."
Natural moisture..................	moisture content representative of field conditions at time sample was taken.
Natural density....................	dry unit weight of sample representative of in-place undisturbed condition.

LABORATORY INVESTIGATIONS, continued

Direct shear........................soil shearing strength under varying load and/or moisture conditions. For use in foundation design and slope stability evaluation.

Permeability........................the rate at which fluid (water) will flow through soil or rock.

Moisture-density relationship.......the optimum (best) moisture content for compacting soil and the maximum dry unit weight (density) for a given compactive effort.

The results of all field and laboratory tests are summarized on the enclosed Table and Plates. This information, along with the field observations, was used to prepare the final test boring logs shown in the Appendix. Sampling and testing procedures are further described in the Appendix.

SUBSURFACE CONDITIONS

The natural soil profile consists generally of clay underlain by claystone shale. The silty clay is very stiff and has moderate shear strength. The claystone shale bedrock is slightly weathered and fractured near the contact zone, then becomes competent with depth. It contains interbedded seams of bentonite and sandy and siltstone shales. An exception to the above profile was encountered in Drill Hole 6, where bedrock was not reached.

FINDINGS

We understand the landfill operation will consist of excavating the natural materials to a specified level, placing the refuse, and eventually providing a soil cover to limit the infiltration of water into the refuse.

Excavations will be in clay and shale. These materials are generally stable at moderate slopes, and can be excavated by conventional means. A ripper may be required in the more competent shale. Permeability tests on both in-place and remolded samples indicate the in-place shale has a very low permeability and will be an excellent material for the base of the landfill. If the landfill base is in the clay stratum, it will require overexcavation and recompaction so sandy seams can be intermixed with the clay. As indicated by the test results shown below, the clay has low to very low permeability characteristics when compacted, and the shale is practically impermeable:

FINDINGS, continued

Material	Location and Depth in Feet	Condition	Permeability, cm/sec.
Clay	DH 2, 2.2 - 12.2	Remolded*	2×10^{-4}
Clay	DH 6, 2.4 - 12.4	Remolded*	6×10^{-7}
Clay	DH 6, 8.0 - 8.5	Undisturbed (lab)	1×10^{-6}
Shale	DH 1, 22.6 - 32.1	Remolded*	5×10^{-7}
Shale	DH 5, 22.5 - 24.0	Undisturbed (lab)	2×10^{-6}
Shale	DH 5, 33.3 - 40.3	In-place (field)	3×10^{-6}

*Samples were remolded at optimum moisture content to 90 percent of maximum dry density as determined by ASTM D698.

Permeability values (K) can be evaluated using the following criteria:

K in cm/sec.	
Greater than 10^{-3}	Permeable
10^{-3} to 10^{-5}	Low
10^{-5} to 10^{-7}	Very Low
10^{-7}	Practically Impermeable

Both the clay and shale, when compacted, are suitable for cover material.

CONCLUSIONS

Based on a minimum number of tests and past experience with soils having similar physical properties, general guidelines for planning are as follows:

1. Permanent cutslopes in either the silty clay or the claystone shale should not be steeper than 2:1 (horizontal to vertical).

CONCLUSIONS, continued

2. Fill slopes will vary, depending on the soil density and the refuse content. If uncontaminated (no refuse) materials are placed in 8-inch lifts and compacted at optimum moisture content to at least 90 percent of the maximum dry density determined by ASTM D698, slopes should not be steeper than 2-1/2:1.

3. The in-place materials can be excavated to the depths of our test borings using conventional excavation equipment.

4. Both the shale or clay, compacted to 90 percent of its maximum dry density, can be used for cover material.

5. If clay is encountered at the base elevation, it should be excavated an additional 24 inches, replaced in 8-inch lifts, and compacted to 95 percent of the maximum dry density as determined by ASTM D698.

If you have any questions concerning this report, please contact us at your convenience.

Respectfully submitted,

Larry G. O'Dell, P. E.

LGO/mb
Enclosures
In triplicate

Appendix B

LandGEM Results for 2007 NMOC Evaluation

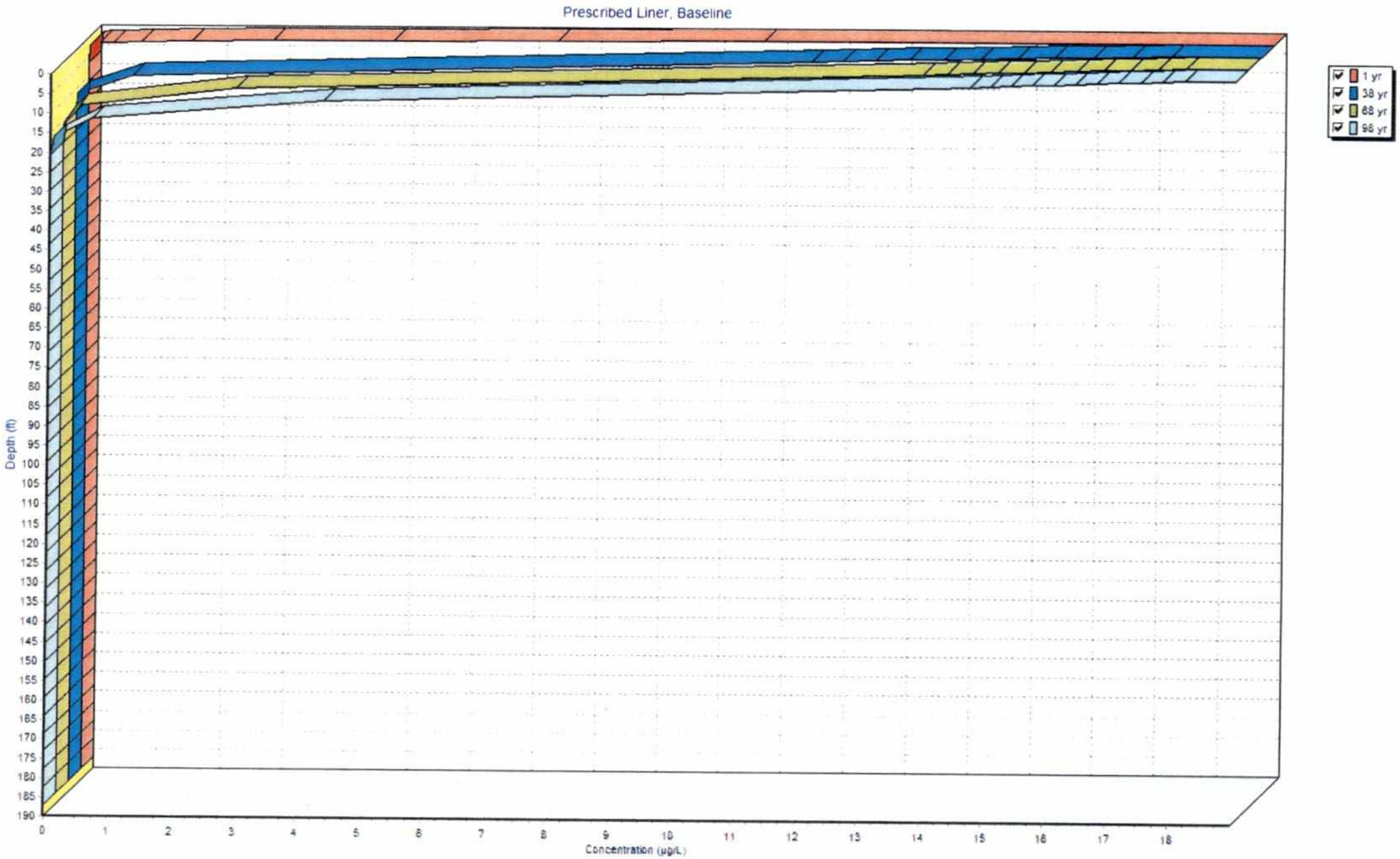
INVENTORY

Landfill Name or Identifier: Billings Regional Landfill

Enter year of emissions inventory: 2048

Gas / Pollutant	Emission Rate				
	(Mg/year)	*(m^3/year)*	*(av ft^3/min)*	*(ft^3/year)*	*(short tons/year)*
Total landfill gas	5.019E+04	4.019E+07	2.700E+03	1.419E+09	5.521E+04
Methane	1.341E+04	2.010E+07	1.350E+03	7.097E+08	1.475E+04
Carbon dioxide	3.679E+04	2.010E+07	1.350E+03	7.097E+08	4.046E+04
NMOC	8.946E+01	2.496E+04	1.677E+00	8.814E+05	9.841E+01
1,1,1-Trichloroethane (methyl chloroform) - HAP	1.070E-01	1.929E+01	1.296E-03	6.813E+02	1.178E-01
1,1,2,2-Tetrachloroethane - HAP/VOC	3.087E-01	4.421E+01	2.971E-03	1.561E+03	3.395E-01
1,1-Dichloroethane (ethylidene dichloride) - HAP/VOC	3.971E-01	9.646E+01	6.481E-03	3.406E+03	4.368E-01
1,1-Dichloroethene (vinylidene chloride) - HAP/VOC	3.241E-02	8.038E+00	5.401E-04	2.839E+02	3.565E-02
1,2-Dichloroethane (ethylene dichloride) - HAP/VOC	6.783E-02	1.648E+01	1.107E-03	5.819E+02	7.461E-02

Appendix C
POLLUTE Model Results



Prescribed liner, 98-year run.

POLLUTEv7

Version 7.11

Prescribed Liner, Baseline

THE DARCY VELOCITY (Flux) THROUGH THE LAYERS Va = 2.182E-6 ft/a

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Geomembrane	60 mil	1	2E-8 cm2/s	1	0 m3/kg	950 kg/m3
Clay Base	2 ft	10	6E-6 cm2/s	0.3	0 mL/g	102.9 lb/ft3
Aquitard	185 ft	10	4E-6 cm2/s	0.254	0 mL/g	102.9 lb/ft3

Boundary Conditions

Finite Mass Top Boundary

Initial Concentration = 19 µg/L
Volume of Leachate Collected = 0.0339999940219178 ft/day
Thickness of Waste = 125 ft
Waste Density = 1200 lb/ft3
Proportion of Mass = 0.001
Reference Height of Leachate = 0 m

Fixed Outflow Bottom Boundary

Landfill Length = 289.56 m
Landfill Width = 1 m
Base Thickness = 1 ft
Base Porosity = 0.3
Base Outflow Velocity = 0.002073 ft/a

Laplace Transform Parameters

TAU = 7   N = 20   SIG = 0   RNU = 2

Calculated Concentrations at Selected Times and Depths

Time yr	Depth ft	Concentration µg/L
1	0.000E+00	1.900E+01
	5.000E-03	1.084E+01
	2.050E-01	7.518E+00
	4.050E-01	4.871E+00
	6.050E-01	2.936E+00
	8.050E-01	1.640E+00
	1.005E+00	8.464E-01
	1.205E+00	4.026E-01
	1.405E+00	1.761E-01
	1.605E+00	7.084E-02
	1.805E+00	2.651E-02
	2.005E+00	1.036E-02
	6.630E+00	1.239E-17
	1.126E+01	1.686E-32
	1.588E+01	4.115E-47
	2.051E+01	0.000E+00
	2.513E+01	0.000E+00
	2.976E+01	0.000E+00
	3.438E+01	0.000E+00
	3.901E+01	0.000E+00
	4.363E+01	0.000E+00
	4.826E+01	0.000E+00
	5.288E+01	0.000E+00
	5.751E+01	0.000E+00
	6.213E+01	0.000E+00
	6.676E+01	0.000E+00
	7.138E+01	0.000E+00
	7.601E+01	0.000E+00
	8.063E+01	0.000E+00
	8.526E+01	0.000E+00
	8.988E+01	0.000E+00
	9.451E+01	0.000E+00
	9.913E+01	0.000E+00
	1.038E+02	0.000E+00
	1.084E+02	0.000E+00
	1.130E+02	0.000E+00
	1.176E+02	0.000E+00

	1.223E+02 1.269E+02 1.315E+02 1.361E+02 1.408E+02 1.454E+02 1.500E+02 1.546E+02 1.593E+02 1.639E+02 1.685E+02 1.731E+02 1.778E+02 1.824E+02 1.870E+02	0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
10	0.000E+00 5.000E-03 2.050E-01 4.050E-01 6.050E-01 8.050E-01 1.005E+00 1.205E+00 1.405E+00 1.605E+00 1.805E+00 2.005E+00 6.630E+00 1.126E+01 1.588E+01 2.051E+01 2.513E+01 2.976E+01 3.438E+01 3.901E+01 4.363E+01 4.826E+01 5.288E+01 5.751E+01 6.213E+01 6.676E+01 7.138E+01 7.601E+01 8.063E+01 8.526E+01 8.988E+01 9.451E+01	1.900E+01 1.584E+01 1.446E+01 1.312E+01 1.184E+01 1.063E+01 9.502E+00 8.462E+00 7.517E+00 6.669E+00 5.922E+00 5.276E+00 1.690E-03 3.551E-10 2.779E-14 1.277E-17 5.545E-22 1.592E-27 6.862E-32 8.490E-36 2.313E-40 1.487E-45 7.097E-50 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

	9.913E+01 1.038E+02 1.084E+02 1.130E+02 1.176E+02 1.223E+02 1.269E+02 1.315E+02 1.361E+02 1.408E+02 1.454E+02 1.500E+02 1.546E+02 1.593E+02 1.639E+02 1.685E+02 1.731E+02 1.778E+02 1.824E+02 1.870E+02	0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
20	0.000E+00 5.000E-03 2.050E-01 4.050E-01 6.050E-01 8.050E-01 1.005E+00 1.205E+00 1.405E+00 1.605E+00 1.805E+00 2.005E+00 6.630E+00 1.126E+01 1.588E+01 2.051E+01 2.513E+01 2.976E+01 3.438E+01 3.901E+01 4.363E+01 4.826E+01 5.288E+01 5.751E+01 6.213E+01 6.676E+01 7.138E+01	1.900E+01 1.687E+01 1.593E+01 1.501E+01 1.412E+01 1.325E+01 1.241E+01 1.162E+01 1.086E+01 1.015E+01 9.481E+00 8.862E+00 1.092E-01 3.775E-05 3.106E-10 1.761E-13 1.474E-15 4.197E-18 3.581E-21 7.833E-25 6.090E-29 1.018E-31 2.124E-34 2.144E-37 9.806E-41 2.073E-44 7.757E-48

	7.601E+01 8.063E+01 8.526E+01 8.988E+01 9.451E+01 9.913E+01 1.038E+02 1.084E+02 1.130E+02 1.176E+02 1.223E+02 1.269E+02 1.315E+02 1.361E+02 1.408E+02 1.454E+02 1.500E+02 1.546E+02 1.593E+02 1.639E+02 1.685E+02 1.731E+02 1.778E+02 1.824E+02 1.870E+02	1.171E-50 0.000E+00
30	0.000E+00 5.000E-03 2.050E-01 4.050E-01 6.050E-01 8.050E-01 1.005E+00 1.205E+00 1.405E+00 1.605E+00 1.805E+00 2.005E+00 6.630E+00 1.126E+01 1.588E+01 2.051E+01 2.513E+01 2.976E+01 3.438E+01 3.901E+01 4.363E+01 4.826E+01	1.899E+01 1.734E+01 1.661E+01 1.589E+01 1.518E+01 1.449E+01 1.382E+01 1.316E+01 1.253E+01 1.192E+01 1.134E+01 1.079E+01 4.742E-01 2.008E-03 7.136E-07 2.414E-11 1.708E-13 3.693E-15 3.938E-17 1.942E-19 4.094E-22 3.380E-25

	5.288E+01 5.751E+01 6.213E+01 6.676E+01 7.138E+01 7.601E+01 8.063E+01 8.526E+01 8.988E+01 9.451E+01 9.913E+01 1.038E+02 1.084E+02 1.130E+02 1.176E+02 1.223E+02 1.269E+02 1.315E+02 1.361E+02 1.408E+02 1.454E+02 1.500E+02 1.546E+02 1.593E+02 1.639E+02 1.685E+02 1.731E+02 1.778E+02 1.824E+02 1.870E+02	1.370E-28 5.059E-31 3.970E-33 1.984E-35 6.010E-38 1.066E-40 1.111E-43 1.163E-46 4.435E-49 0.000E+00
40	0.000E+00 5.000E-03 2.050E-01 4.050E-01 6.050E-01 8.050E-01 1.005E+00 1.205E+00 1.405E+00 1.605E+00 1.805E+00 2.005E+00 6.630E+00 1.126E+01 1.588E+01 2.051E+01 2.513E+01	1.899E+01 1.761E+01 1.700E+01 1.640E+01 1.580E+01 1.522E+01 1.464E+01 1.408E+01 1.353E+01 1.300E+01 1.249E+01 1.199E+01 1.018E+00 1.529E-02 3.649E-05 1.318E-08 2.515E-12

	2.976E+01 3.438E+01 3.901E+01 4.363E+01 4.826E+01 5.288E+01 5.751E+01 6.213E+01 6.676E+01 7.138E+01 7.601E+01 8.063E+01 8.526E+01 8.988E+01 9.451E+01 9.913E+01 1.038E+02 1.084E+02 1.130E+02 1.176E+02 1.223E+02 1.269E+02 1.315E+02 1.361E+02 1.408E+02 1.454E+02 1.500E+02 1.546E+02 1.593E+02 1.639E+02 1.685E+02 1.731E+02 1.778E+02 1.824E+02 1.870E+02	1.035E-13 3.583E-15 7.296E-17 8.385E-19 5.178E-21 1.622E-23 2.470E-26 3.296E-29 3.650E-31 5.498E-33 5.904E-35 4.375E-37 2.188E-39 7.251E-42 1.688E-44 5.175E-47 4.489E-49 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
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	6.630E+00 1.126E+01 1.588E+01 2.051E+01 2.513E+01 2.976E+01 3.438E+01 3.901E+01 4.363E+01 4.826E+01 5.288E+01 5.751E+01 6.213E+01 6.676E+01 7.138E+01 7.601E+01 8.063E+01 8.526E+01 8.988E+01 9.451E+01 9.913E+01 1.038E+02 1.084E+02 1.130E+02 1.176E+02 1.223E+02 1.269E+02 1.315E+02 1.361E+02 1.408E+02 1.454E+02 1.500E+02 1.546E+02 1.593E+02 1.639E+02 1.685E+02 1.731E+02 1.778E+02 1.824E+02 1.870E+02	1.633E+00 5.287E-02 3.975E-04 6.654E-07 2.496E-10 7.758E-13 5.191E-14 2.378E-15 7.099E-17 1.340E-18 1.546E-20 1.046E-22 3.985E-25 9.143E-28 5.020E-30 1.221E-31 2.703E-33 4.522E-35 5.618E-37 5.098E-39 3.332E-41 1.589E-43 7.003E-46 6.381E-48 1.062E-49 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
60	0.000E+00 5.000E-03 2.050E-01 4.050E-01 6.050E-01 8.050E-01 1.005E+00	1.899E+01 1.792E+01 1.744E+01 1.697E+01 1.650E+01 1.604E+01 1.558E+01

	1.205E+00	1.513E+01
	1.405E+00	1.468E+01
	1.605E+00	1.425E+01
	1.805E+00	1.382E+01
	2.005E+00	1.341E+01
	6.630E+00	2.256E+00
	1.126E+01	1.224E-01
	1.588E+01	1.986E-03
	2.051E+01	9.269E-06
	2.513E+01	1.222E-08
	2.976E+01	7.320E-12
	3.438E+01	3.062E-13
	3.901E+01	2.369E-14
	4.363E+01	1.305E-15
	4.826E+01	5.006E-17
	5.288E+01	1.308E-18
	5.751E+01	2.265E-20
	6.213E+01	2.522E-22
	6.676E+01	1.748E-24
	7.138E+01	7.549E-27
	7.601E+01	3.501E-29
	8.063E+01	8.063E-31
	8.526E+01	2.787E-32
	8.988E+01	7.882E-34
	9.451E+01	1.755E-35
	9.913E+01	3.040E-37
	1.038E+02	4.046E-39
	1.084E+02	4.094E-41
	1.130E+02	3.173E-43
	1.176E+02	2.171E-45
	1.223E+02	2.360E-47
	1.269E+02	5.140E-49
	1.315E+02	1.227E-50
	1.361E+02	0.000E+00
	1.408E+02	0.000E+00
	1.454E+02	0.000E+00
	1.500E+02	0.000E+00
	1.546E+02	0.000E+00
	1.593E+02	0.000E+00
	1.639E+02	0.000E+00
	1.685E+02	0.000E+00
	1.731E+02	0.000E+00
	1.778E+02	0.000E+00
	1.824E+02	0.000E+00
	1.870E+02	0.000E+00
70	0.000E+00	1.899E+01
	5.000E-03	1.801E+01

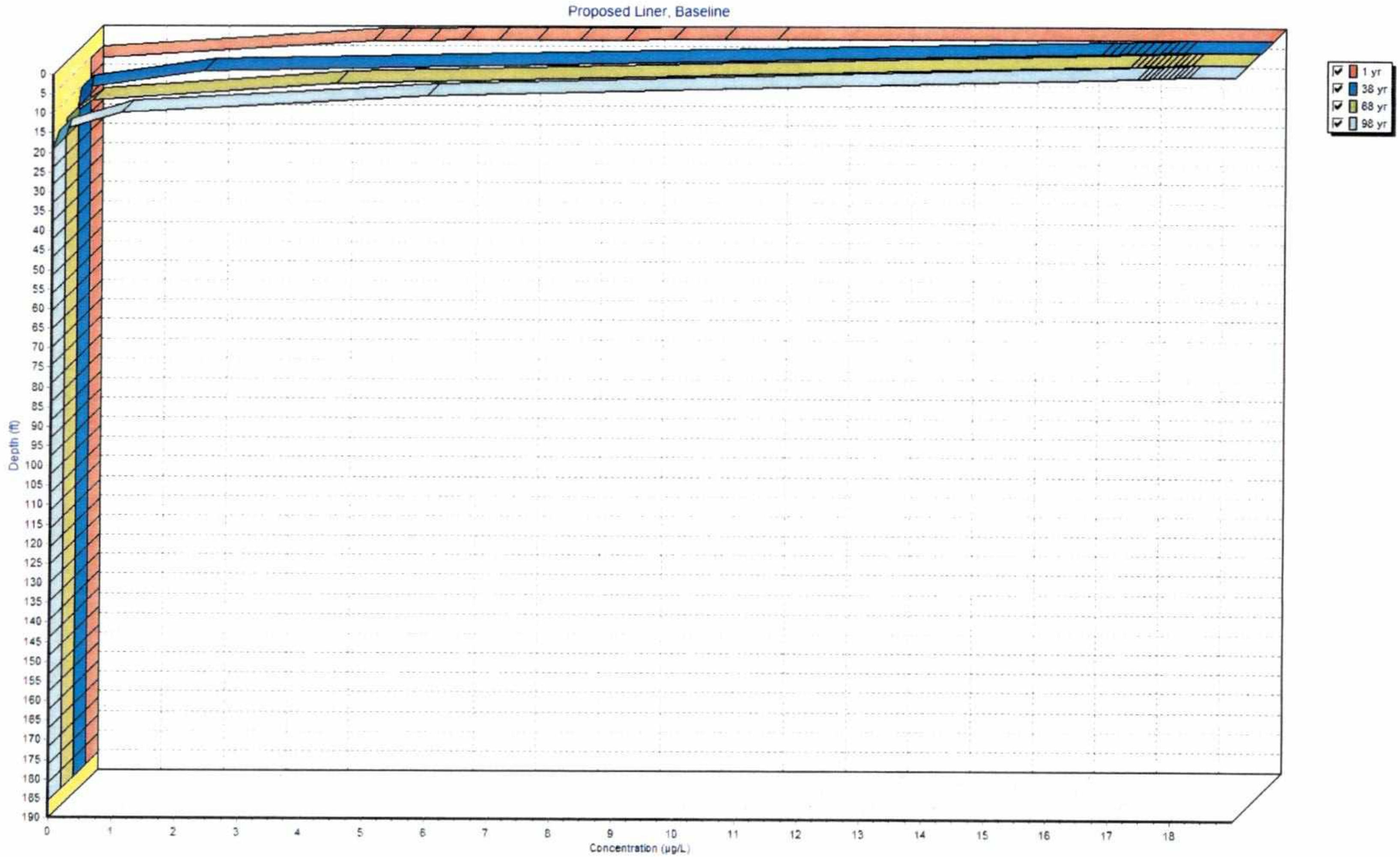
	2.050E-01	1.758E+01
	4.050E-01	1.715E+01
	6.050E-01	1.672E+01
	8.050E-01	1.629E+01
	1.005E+00	1.587E+01
	1.205E+00	1.546E+01
	1.405E+00	1.505E+01
	1.605E+00	1.465E+01
	1.805E+00	1.425E+01
	2.005E+00	1.386E+01
	6.630E+00	2.856E+00
	1.126E+01	2.249E-01
	1.588E+01	6.331E-03
	2.051E+01	6.160E-05
	2.513E+01	2.033E-07
	2.976E+01	2.322E-10
	3.438E+01	1.166E-12
	3.901E+01	1.213E-13
	4.363E+01	1.023E-14
	4.826E+01	6.409E-16
	5.288E+01	2.933E-17
	5.751E+01	9.623E-19
	6.213E+01	2.215E-20
	6.676E+01	3.490E-22
	7.138E+01	3.670E-24
	7.601E+01	2.548E-26
	8.063E+01	1.486E-28
	8.526E+01	2.788E-30
	8.988E+01	1.246E-31
	9.451E+01	5.071E-33
	9.913E+01	1.694E-34
	1.038E+02	4.593E-36
	1.084E+02	1.000E-37
	1.130E+02	1.733E-39
	1.176E+02	2.371E-41
	1.223E+02	2.589E-43
	1.269E+02	2.554E-45
	1.315E+02	3.677E-47
	1.361E+02	1.008E-48
	1.408E+02	3.223E-50
	1.454E+02	0.000E+00
	1.500E+02	0.000E+00
	1.546E+02	0.000E+00
	1.593E+02	0.000E+00
	1.639E+02	0.000E+00
	1.685E+02	0.000E+00
	1.731E+02	0.000E+00
	1.778E+02	0.000E+00

	1.824E+02 1.870E+02	0.000E+00 0.000E+00
80	0.000E+00 5.000E-03 2.050E-01 4.050E-01 6.050E-01 8.050E-01 1.005E+00 1.205E+00 1.405E+00 1.605E+00 1.805E+00 2.005E+00 6.630E+00 1.126E+01 1.588E+01 2.051E+01 2.513E+01 2.976E+01 3.438E+01 3.901E+01 4.363E+01 4.826E+01 5.288E+01 5.751E+01 6.213E+01 6.676E+01 7.138E+01 7.601E+01 8.063E+01 8.526E+01 8.988E+01 9.451E+01 9.913E+01 1.038E+02 1.084E+02 1.130E+02 1.176E+02 1.223E+02 1.269E+02 1.315E+02 1.361E+02 1.408E+02 1.454E+02 1.500E+02 1.546E+02	1.899E+01 1.808E+01 1.768E+01 1.728E+01 1.689E+01 1.649E+01 1.610E+01 1.572E+01 1.534E+01 1.496E+01 1.459E+01 1.423E+01 3.420E+00 3.568E-01 1.521E-02 2.571E-04 1.693E-06 4.308E-09 6.963E-12 4.130E-13 4.753E-14 4.264E-15 2.935E-16 1.529E-17 5.930E-19 1.682E-20 3.419E-22 4.877E-24 4.828E-26 3.799E-28 6.537E-30 3.332E-31 1.765E-32 7.948E-34 2.991E-35 9.336E-37 2.397E-38 5.023E-40 8.557E-42 1.207E-43 1.621E-45 3.200E-47 1.112E-48 4.455E-50 0.000E+00

	1.593E+02	0.000E+00
	1.639E+02	0.000E+00
	1.685E+02	0.000E+00
	1.731E+02	0.000E+00
	1.778E+02	0.000E+00
	1.824E+02	0.000E+00
	1.870E+02	0.000E+00

NOTICE

Although this program has been tested and experience would indicate that it is accurate within the limits given by the assumptions of the theory used, we make no warranty as to workability of this software or any other licensed material. No warranties either expressed or implied (including warranties of fitness) shall apply. No responsibility is assumed for any errors, mistakes or misrepresentations that may occur from the use of this computer program. The user accepts full responsibility for assessing the validity and applicability of the results obtained with this program for any specific case.



Proposed liner, 98-year run

POLLUTEv7

Version 7.11

Proposed Liner, Baseline

THE DARCY VELOCITY (Flux) THROUGH THE LAYERS Va = 1.092E-6 ft/a

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Geomembrane	60 mil	1	2E-8 cm2/s	1	0 m3/kg	950 kg/m3
Clay Base	0.5 ft	10	6E-6 cm2/s	0.3	0 mL/g	102.9 lb/ft3
Aquitard	185 ft	10	4E-6 cm2/s	0.254	0 mL/g	102.9 lb/ft3

Boundary Conditions

Finite Mass Top Boundary

Initial Concentration = 19 µg/L
Volume of Leachate Collected = 0.0339999970082192 ft/day
Thickness of Waste = 125 ft
Waste Density = 1200 lb/ft3
Proportion of Mass = 0.001
Reference Height of Leachate = 0 m

Fixed Outflow Bottom Boundary

Landfill Length = 289.56 m
Landfill Width = 1 m
Base Thickness = 1 ft
Base Porosity = 0.3
Base Outflow Velocity = 0.002073 ft/a

Laplace Transform Parameters

TAU = 7 N = 20 SIG = 0 RNU = 2

Calculated Concentrations at Selected Times and Depths

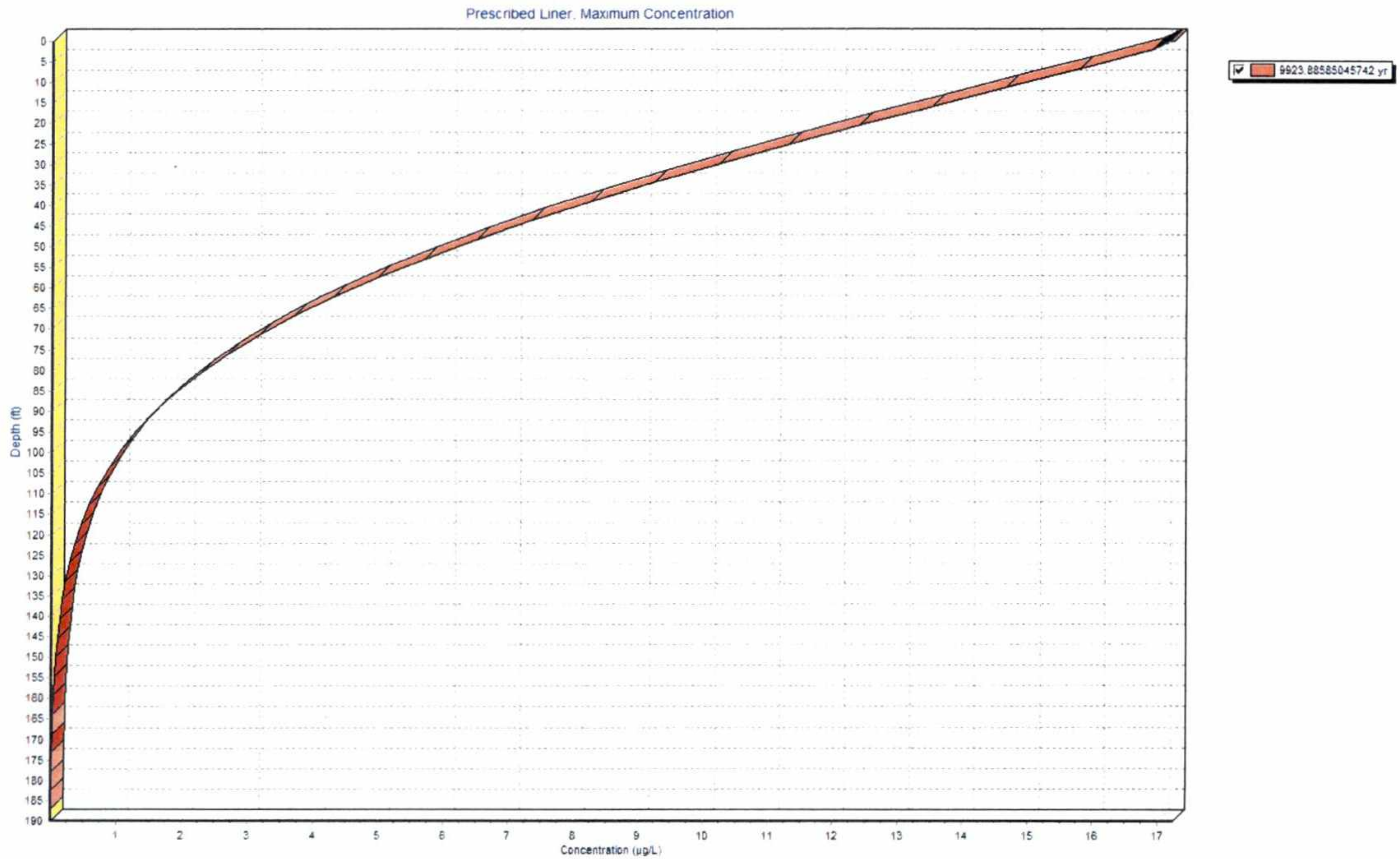
Time yr	Depth ft	Concentration µg/L
1	0.000E+00	1.900E+01
	5.000E-03	1.103E+01
	5.500E-02	1.017E+01
	1.050E-01	9.348E+00
	1.550E-01	8.570E+00
	2.050E-01	7.839E+00
	2.550E-01	7.157E+00
	3.050E-01	6.525E+00
	3.550E-01	5.946E+00
	4.050E-01	5.418E+00
	4.550E-01	4.944E+00
	5.050E-01	4.522E+00
	5.130E+00	8.444E-15
	9.755E+00	2.709E-29
	1.438E+01	8.482E-43
	1.901E+01	0.000E+00
	2.363E+01	0.000E+00
	2.826E+01	0.000E+00
	3.288E+01	0.000E+00
	3.751E+01	0.000E+00
	4.213E+01	0.000E+00
	4.676E+01	0.000E+00
	5.138E+01	0.000E+00
	5.601E+01	0.000E+00
	6.063E+01	0.000E+00
	6.526E+01	0.000E+00
	6.988E+01	0.000E+00
	7.451E+01	0.000E+00
	7.913E+01	0.000E+00
	8.376E+01	0.000E+00
	8.838E+01	0.000E+00
	9.301E+01	0.000E+00
	9.763E+01	0.000E+00
	1.023E+02	0.000E+00
	1.069E+02	0.000E+00
	1.115E+02	0.000E+00
	1.161E+02	0.000E+00
	1.208E+02	0.000E+00

	1.254E+02 1.300E+02 1.346E+02 1.393E+02 1.439E+02 1.485E+02 1.531E+02 1.578E+02 1.624E+02 1.670E+02 1.716E+02 1.763E+02 1.809E+02 1.855E+02	0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
38	0.000E+00 5.000E-03 5.500E-02 1.050E-01 1.550E-01 2.050E-01 2.550E-01 3.050E-01 3.550E-01 4.050E-01 4.550E-01 5.050E-01 5.130E+00 9.755E+00 1.438E+01 1.901E+01 2.363E+01 2.826E+01 3.288E+01 3.751E+01 4.213E+01 4.676E+01 5.138E+01 5.601E+01 6.063E+01 6.526E+01 6.988E+01 7.451E+01 7.913E+01 8.376E+01 8.838E+01 9.301E+01 9.763E+01	1.899E+01 1.777E+01 1.764E+01 1.750E+01 1.737E+01 1.723E+01 1.710E+01 1.697E+01 1.683E+01 1.670E+01 1.657E+01 1.643E+01 2.004E+00 4.149E-02 1.251E-04 5.169E-08 5.255E-12 1.361E-13 4.560E-15 8.767E-17 9.254E-19 5.086E-21 1.368E-23 1.722E-26 2.097E-29 2.310E-31 3.021E-33 2.747E-35 1.684E-37 6.793E-40 1.777E-42 3.418E-45 1.200E-47

	1.023E+02 1.069E+02 1.115E+02 1.161E+02 1.208E+02 1.254E+02 1.300E+02 1.346E+02 1.393E+02 1.439E+02 1.485E+02 1.531E+02 1.578E+02 1.624E+02 1.670E+02 1.716E+02 1.763E+02 1.809E+02 1.855E+02	1.058E-49 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
68	0.000E+00 5.000E-03 5.500E-02 1.050E-01 1.550E-01 2.050E-01 2.550E-01 3.050E-01 3.550E-01 4.050E-01 4.550E-01 5.050E-01 5.130E+00 9.755E+00 1.438E+01 1.901E+01 2.363E+01 2.826E+01 3.288E+01 3.751E+01 4.213E+01 4.676E+01 5.138E+01 5.601E+01 6.063E+01 6.526E+01 6.988E+01 7.451E+01	1.899E+01 1.808E+01 1.798E+01 1.788E+01 1.778E+01 1.768E+01 1.758E+01 1.748E+01 1.738E+01 1.728E+01 1.718E+01 1.709E+01 4.322E+00 4.223E-01 1.453E-02 1.683E-04 6.409E-07 8.012E-10 1.729E-12 1.604E-13 1.362E-14 8.537E-16 3.884E-17 1.258E-18 2.834E-20 4.333E-22 4.374E-24 2.877E-26

	7.913E+01 8.376E+01 8.838E+01 9.301E+01 9.763E+01 1.023E+02 1.069E+02 1.115E+02 1.161E+02 1.208E+02 1.254E+02 1.300E+02 1.346E+02 1.393E+02 1.439E+02 1.485E+02 1.531E+02 1.578E+02 1.624E+02 1.670E+02 1.716E+02 1.763E+02 1.809E+02 1.855E+02	1.545E-28 2.653E-30 1.132E-31 4.385E-33 1.387E-34 3.535E-36 7.190E-38 1.155E-39 1.454E-41 1.458E-43 1.360E-45 2.015E-47 5.533E-49 1.668E-50 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
98	0.000E+00 5.000E-03 5.500E-02 1.050E-01 1.550E-01 2.050E-01 2.550E-01 3.050E-01 3.550E-01 4.050E-01 4.550E-01 5.050E-01 5.130E+00 9.755E+00 1.438E+01 1.901E+01 2.363E+01 2.826E+01 3.288E+01 3.751E+01 4.213E+01 4.676E+01 5.138E+01	1.898E+01 1.823E+01 1.815E+01 1.807E+01 1.798E+01 1.790E+01 1.782E+01 1.773E+01 1.765E+01 1.757E+01 1.748E+01 1.740E+01 5.991E+00 1.084E+00 9.675E-02 4.110E-03 8.147E-05 7.449E-07 3.130E-09 8.819E-12 5.253E-13 7.735E-14 9.384E-15

	5.601E+01	9.209E-16
	6.063E+01	7.237E-17
	6.526E+01	4.505E-18
	6.988E+01	2.194E-19
	7.451E+01	8.240E-21
	7.913E+01	2.351E-22
	8.376E+01	5.017E-24
	8.838E+01	7.936E-26
	9.301E+01	9.963E-28
	9.763E+01	1.814E-29
	1.023E+02	1.001E-30
	1.069E+02	7.333E-32
	1.115E+02	4.852E-33
	1.161E+02	2.788E-34
	1.208E+02	1.381E-35
	1.254E+02	5.865E-37
	1.300E+02	2.122E-38
	1.346E+02	6.506E-40
	1.393E+02	1.684E-41
	1.439E+02	3.709E-43
	1.485E+02	7.425E-45
	1.531E+02	1.733E-46
	1.578E+02	6.596E-48
	1.624E+02	3.488E-49
	1.670E+02	1.884E-50
	1.716E+02	0.000E+00
	1.763E+02	0.000E+00
	1.809E+02	0.000E+00
	1.855E+02	0.000E+00



Prescribed liner, maximum concentration, 10,000-year run.

POLLUTEv7

Version 7.11

Prescribed Liner, Maximum Concentration

THE DARCY VELOCITY (Flux) THROUGH THE LAYERS Va = 2.182E-6 ft/a

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Geomembrane	60 mil	1	2E-8 cm2/s	1	0 m3/kg	950 kg/m3
Clay Base	2 ft	10	6E-6 cm2/s	0.3	0 mL/g	102.9 lb/ft3
Aquitard	185 ft	10	4E-6 cm2/s	0.254	0 mL/g	102.9 lb/ft3

Boundary Conditions

Finite Mass Top Boundary

Initial Concentration = 19 µg/L
Volume of Leachate Collected = 0.0339999940219178 ft/day
Thickness of Waste = 125 ft
Waste Density = 1200 lb/ft3
Proportion of Mass = 0.001
Reference Height of Leachate = 0 m

Fixed Outflow Bottom Boundary

Landfill Length = 289.56 m
Landfill Width = 1 m
Base Thickness = 1 ft
Base Porosity = 0.3
Base Outflow Velocity = 0.002073 ft/a

Laplace Transform Parameters

TAU = 7   **N** = 20   **SIG** = 0   **RNU** = 2

Maximum Base Concentration Parameters

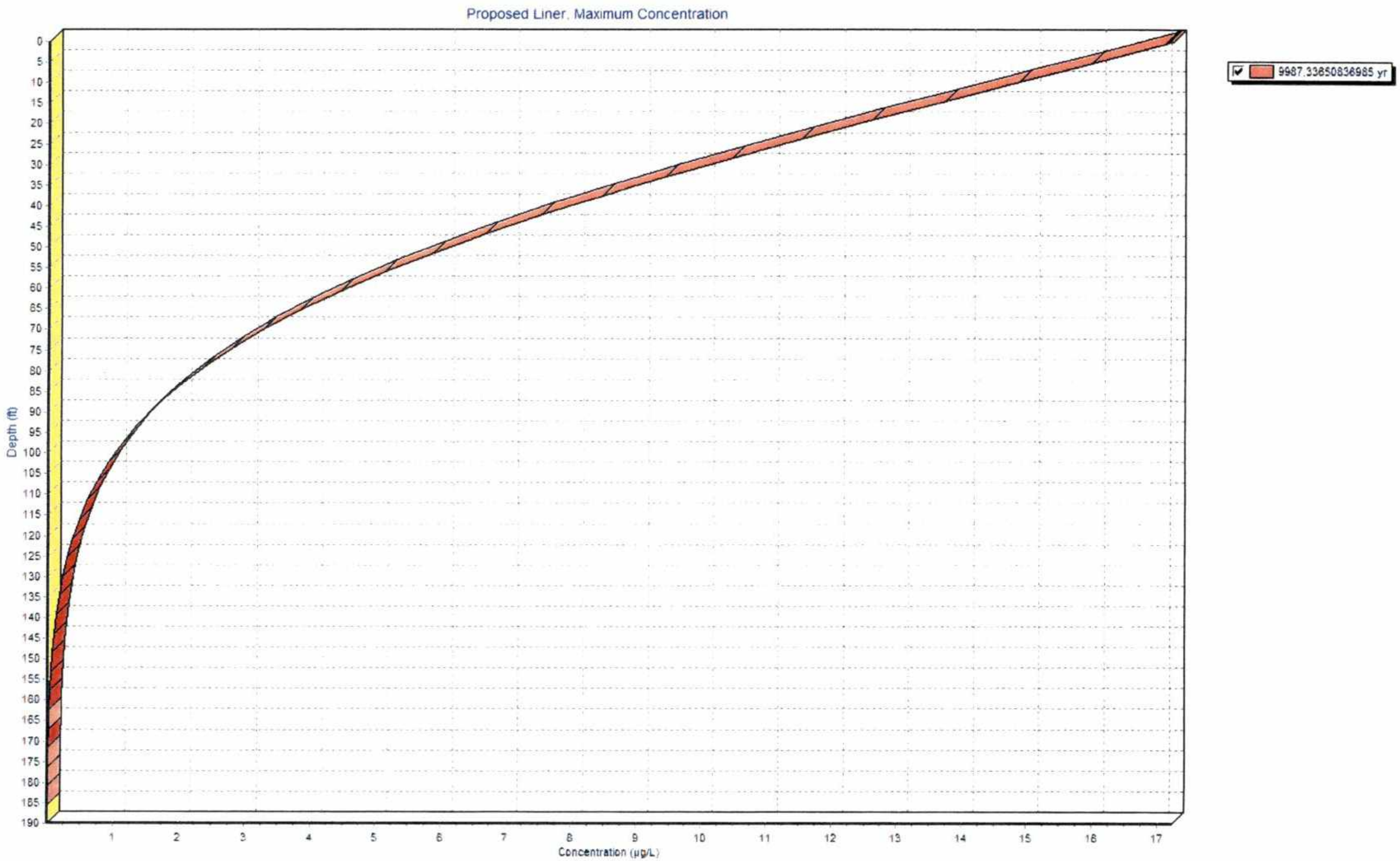
Depth to Search = 85 ft
Lower Time Limit = 1 year
Upper Time Limit = 10000 year
Base Concentration Accuracy = 0.25
Maximum Search Attempts = 25

Maximum Base Concentration and Time of Occurrence

Time yr	Depth ft	Concentration µg/L	Preceeding Time	Preceeding Concentration	Exceeding Time	Exceeding Concentration
9.9239E+03	0.0000E+00	1.7237E+01				
	5.0000E-03	1.7177E+01				
	2.0500E-01	1.7150E+01				
	4.0500E-01	1.7123E+01				
	6.0500E-01	1.7096E+01				
	8.0500E-01	1.7069E+01				
	1.0050E+00	1.7042E+01				
	1.2050E+00	1.7015E+01				
	1.4050E+00	1.6988E+01				
	1.6050E+00	1.6961E+01				
	1.8050E+00	1.6934E+01				
	2.0050E+00	1.6907E+01				
	6.6300E+00	1.5788E+01				
	1.1255E+01	1.4658E+01				
	1.5880E+01	1.3529E+01				
	2.0505E+01	1.2413E+01				
	2.5130E+01	1.1320E+01				
	2.9755E+01	1.0260E+01				
	3.4380E+01	9.2417E+00				
	3.9005E+01	8.2720E+00				
	4.3630E+01	7.3570E+00				
	4.8255E+01	6.5011E+00				
	5.2880E+01	5.7075E+00				
	5.7505E+01	4.9778E+00				
	6.2130E+01	4.3127E+00				
	6.6755E+01	3.7115E+00				
	7.1380E+01	3.1726E+00				
	7.6005E+01	2.6935E+00				

	8.0630E+01	2.2711E+00					
	8.5255E+01	1.9018E+00					
	8.9880E+01	1.5814E+00					
	9.4505E+01	1.3059E+00					
	9.9130E+01	1.0708E+00					
	1.0376E+02	8.7186E-01					
	1.0838E+02	7.0484E-01					
	1.1301E+02	5.6575E-01					
	1.1763E+02	4.5087E-01					
	1.2226E+02	3.5673E-01					
	1.2688E+02	2.8023E-01					
	1.3151E+02	2.1854E-01					
	1.3613E+02	1.6922E-01					
	1.4076E+02	1.3010E-01					
	1.4538E+02	9.9330E-02					
	1.5001E+02	7.5347E-02					
	1.5463E+02	5.6828E-02					
	1.5926E+02	4.2686E-02					
	1.6388E+02	3.2032E-02					
	1.6851E+02	2.4159E-02					
	1.7313E+02	1.8514E-02					
	1.7776E+02	1.4685E-02					
	1.8238E+02	1.2380E-02					
	1.8701E+02	1.1420E-02	9.9163E+03	1.8994E+00	9.9315E+03	1.9041E+00

Number of Search Attempts = 9



Proposed liner, maximum concentrations, 10,000-year run.

POLLUTEv7

Version 7.11

Proposed Liner, Maximum Concentration

THE DARCY VELOCITY (Flux) THROUGH THE LAYERS Va = 1.092E-6 ft/a

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Geomembrane	60 mil	1	2E-8 cm2/s	1	0 m3/kg	950 kg/m3
Clay Base	0.5 ft	10	6E-6 cm2/s	0.3	0 mL/g	102.9 lb/ft3
Aquitard	185 ft	10	4E-6 cm2/s	0.254	0 mL/g	102.9 lb/ft3

Boundary Conditions

Finite Mass Top Boundary

Initial Concentration = 19 µg/L
Volume of Leachate Collected = 0.0339999970082192 ft/day
Thickness of Waste = 125 ft
Waste Density = 1200 lb/ft3
Proportion of Mass = 0.001
Reference Height of Leachate = 0 m

Fixed Outflow Bottom Boundary

Landfill Length = 289.56 m
Landfill Width = 1 m
Base Thickness = 1 ft
Base Porosity = 0.3
Base Outflow Velocity = 0.002073 ft/a

Laplace Transform Parameters

TAU = 7 **N** = 20 **SIG** = 0 **RNU** = 2

Maximum Base Concentration Parameters

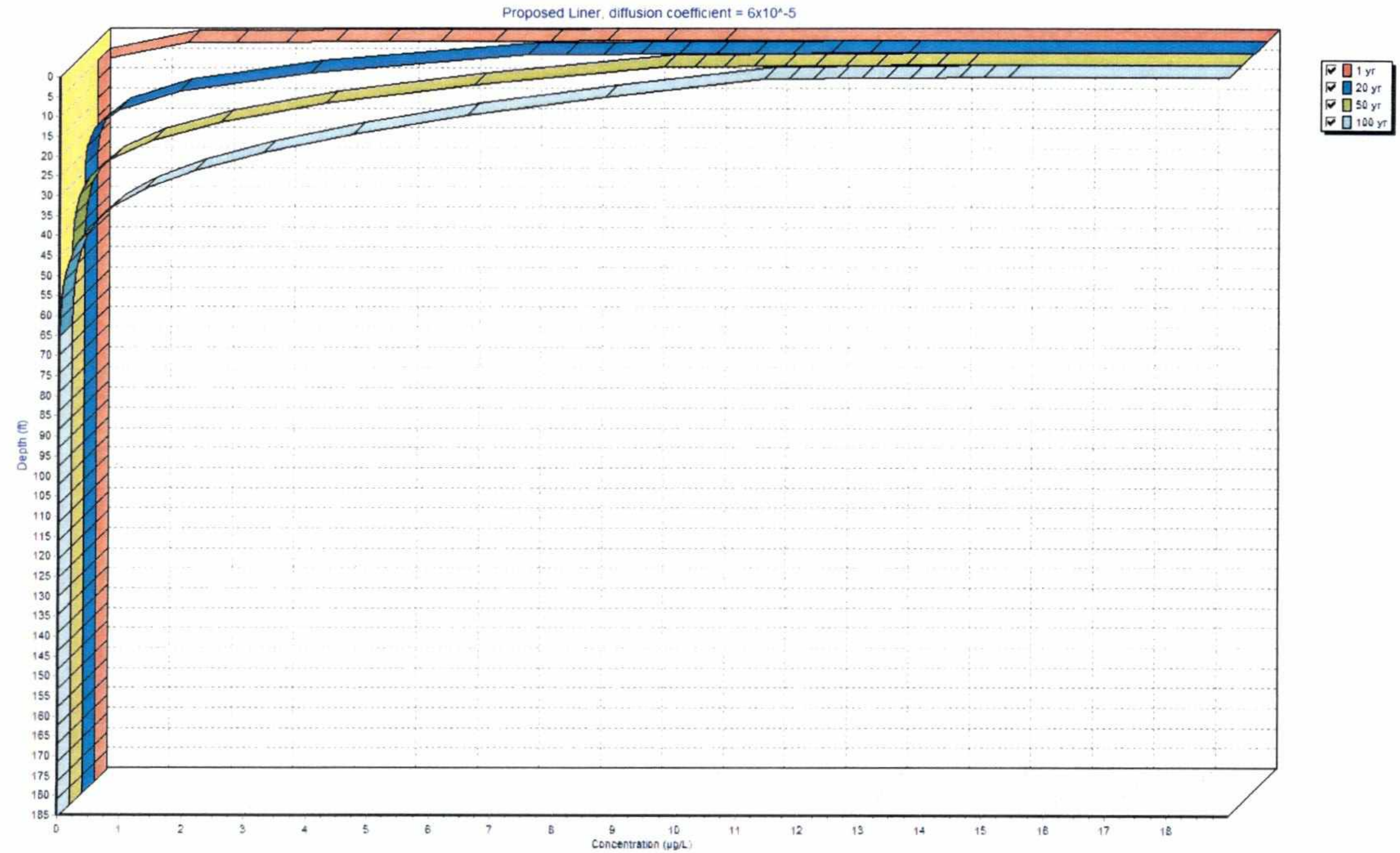
Depth to Search = 190 ft
Lower Time Limit = 1 year
Upper Time Limit = 10000 year
Base Concentration Accuracy = 0.25
Maximum Search Attempts = 25

Maximum Base Concentration and Time of Occurrence

Time yr	Depth ft	Concentration µg/L	Preceeding Time	Preceeding Concentration	Exceeding Time	Exceeding Concentration
9.9873E+03	0.0000E+00	1.7226E+01				
	5.0000E-03	1.7166E+01				
	5.5000E-02	1.7159E+01				
	1.0500E-01	1.7152E+01				
	1.5500E-01	1.7146E+01				
	2.0500E-01	1.7139E+01				
	2.5500E-01	1.7132E+01				
	3.0500E-01	1.7126E+01				
	3.5500E-01	1.7119E+01				
	4.0500E-01	1.7112E+01				
	4.5500E-01	1.7105E+01				
	5.0500E-01	1.7099E+01				
	5.1300E+00	1.5987E+01				
	9.7550E+00	1.4863E+01				
	1.4380E+01	1.3737E+01				
	1.9005E+01	1.2622E+01				
	2.3630E+01	1.1528E+01				
	2.8255E+01	1.0465E+01				
	3.2880E+01	9.4410E+00				
	3.7505E+01	8.4645E+00				
	4.2130E+01	7.5412E+00				
	4.6755E+01	6.6758E+00				
	5.1380E+01	5.8716E+00				
	5.6005E+01	5.1307E+00				
	6.0630E+01	4.4539E+00				
	6.5255E+01	3.8407E+00				
	6.9880E+01	3.2898E+00				
	7.4505E+01	2.7990E+00				

	7.9130E+01	2.3652E+00					
	8.3755E+01	1.9851E+00					
	8.8380E+01	1.6545E+00					
	9.3005E+01	1.3695E+00					
	9.7630E+01	1.1257E+00					
	1.0226E+02	9.1881E-01					
	1.0688E+02	7.4468E-01					
	1.1151E+02	5.9929E-01					
	1.1613E+02	4.7887E-01					
	1.2076E+02	3.7992E-01					
	1.2538E+02	2.9927E-01					
	1.3001E+02	2.3406E-01					
	1.3463E+02	1.8175E-01					
	1.3926E+02	1.4015E-01					
	1.4388E+02	1.0733E-01					
	1.4851E+02	8.1675E-02					
	1.5313E+02	6.1802E-02					
	1.5776E+02	4.6581E-02					
	1.6238E+02	3.5082E-02					
	1.6701E+02	2.6561E-02					
	1.7163E+02	2.0437E-02					
	1.7626E+02	1.6275E-02					
	1.8088E+02	1.3765E-02					
	1.8551E+02	1.2717E-02	9.9861E+03	1.2706E-02	9.9886E+03	1.2728E-02

Number of Search Attempts = 12



Proposed liner, diffusion coefficient increased by an order of magnitude, 100-year run.

POLLUTEv7

Version 7.11

Proposed Liner, diffusion coefficient = 6x10^-5

THE DARCY VELOCITY (Flux) THROUGH THE LAYERS Va = 1.092E-6 ft/a

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Geomembrane	60 mil	1	2E-8 cm2/s	1	0 m3/kg	950 kg/m3
Clay Base	0.5 ft	10	6E-6 cm2/s	0.3	0 mL/g	102.9 lb/ft3
Aquitard	185 ft	10	6E-9 m2/s	0.4	0 mL/g	102.9 lb/ft3

Boundary Conditions

Finite Mass Top Boundary

Initial Concentration = 19 µg/L
Volume of Leachate Collected = 0.0339999970082192 ft/day
Thickness of Waste = 125 ft
Waste Density = 1200 lb/ft3
Proportion of Mass = 0.001
Reference Height of Leachate = 0 m

Fixed Outflow Bottom Boundary

Landfill Length = 289.56 m
Landfill Width = 1 m
Base Thickness = 1 ft
Base Porosity = 0.3
Base Outflow Velocity = 0.002073 ft/a

Laplace Transform Parameters

TAU = 7   N = 20   SIG = 0   RNU = 2

Calculated Concentrations at Selected Times and Depths

Time yr	Depth ft	Concentration µg/L
1	0.000E+00	1.900E+01
	5.000E-03	1.019E+01
	5.500E-02	9.219E+00
	1.050E-01	8.270E+00
	1.550E-01	7.343E+00
	2.050E-01	6.437E+00
	2.550E-01	5.554E+00
	3.050E-01	4.693E+00
	3.550E-01	3.853E+00
	4.050E-01	3.035E+00
	4.550E-01	2.235E+00
	5.050E-01	1.454E+00
	5.130E+00	4.145E-03
	9.755E+00	1.024E-07
	1.438E+01	2.417E-13
	1.901E+01	1.319E-15
	2.363E+01	1.933E-18
	2.826E+01	5.886E-22
	3.288E+01	2.945E-26
	3.751E+01	1.046E-30
	4.213E+01	1.097E-33
	4.676E+01	5.476E-37
	5.138E+01	9.840E-41
	5.601E+01	6.213E-45
	6.063E+01	7.640E-49
	6.526E+01	0.000E+00
	6.988E+01	0.000E+00
	7.451E+01	0.000E+00
	7.913E+01	0.000E+00
	8.376E+01	0.000E+00
	8.838E+01	0.000E+00
	9.301E+01	0.000E+00
	9.763E+01	0.000E+00
	1.023E+02	0.000E+00
	1.069E+02	0.000E+00
	1.115E+02	0.000E+00
	1.161E+02	0.000E+00
	1.208E+02	0.000E+00

	1.254E+02	0.000E+00
	1.300E+02	0.000E+00
	1.346E+02	0.000E+00
	1.393E+02	0.000E+00
	1.439E+02	0.000E+00
	1.485E+02	0.000E+00
	1.531E+02	0.000E+00
	1.578E+02	0.000E+00
	1.624E+02	0.000E+00
	1.670E+02	0.000E+00
	1.716E+02	0.000E+00
	1.763E+02	0.000E+00
	1.809E+02	0.000E+00
	1.855E+02	0.000E+00
20	0.000E+00	1.900E+01
	5.000E-03	1.337E+01
	5.500E-02	1.275E+01
	1.050E-01	1.212E+01
	1.550E-01	1.150E+01
	2.050E-01	1.088E+01
	2.550E-01	1.026E+01
	3.050E-01	9.637E+00
	3.550E-01	9.019E+00
	4.050E-01	8.402E+00
	4.550E-01	7.786E+00
	5.050E-01	7.172E+00
	5.130E+00	3.633E+00
	9.755E+00	1.526E+00
	1.438E+01	5.232E-01
	1.901E+01	1.445E-01
	2.363E+01	3.180E-02
	2.826E+01	5.542E-03
	3.288E+01	7.601E-04
	3.751E+01	8.170E-05
	4.213E+01	6.858E-06
	4.676E+01	4.484E-07
	5.138E+01	2.280E-08
	5.601E+01	9.046E-10
	6.063E+01	2.979E-11
	6.526E+01	1.555E-12
	6.988E+01	3.469E-13
	7.451E+01	1.169E-13
	7.913E+01	3.815E-14
	8.376E+01	1.169E-14
	8.838E+01	3.350E-15
	9.301E+01	8.969E-16
	9.763E+01	2.238E-16

	1.023E+02 1.069E+02 1.115E+02 1.161E+02 1.208E+02 1.254E+02 1.300E+02 1.346E+02 1.393E+02 1.439E+02 1.485E+02 1.531E+02 1.578E+02 1.624E+02 1.670E+02 1.716E+02 1.763E+02 1.809E+02 1.855E+02	5.197E-17 1.120E-17 2.238E-18 4.130E-19 7.027E-20 1.099E-20 1.576E-21 2.066E-22 2.469E-23 2.680E-24 2.640E-25 2.365E-26 1.960E-27 1.613E-28 1.607E-29 2.415E-30 4.964E-31 1.143E-31 3.952E-32
50	0.000E+00 5.000E-03 5.500E-02 1.050E-01 1.550E-01 2.050E-01 2.550E-01 3.050E-01 3.550E-01 4.050E-01 4.550E-01 5.050E-01 5.130E+00 9.755E+00 1.438E+01 1.901E+01 2.363E+01 2.826E+01 3.288E+01 3.751E+01 4.213E+01 4.676E+01 5.138E+01 5.601E+01 6.063E+01 6.526E+01 6.988E+01 7.451E+01	1.899E+01 1.453E+01 1.403E+01 1.354E+01 1.304E+01 1.255E+01 1.205E+01 1.156E+01 1.107E+01 1.057E+01 1.008E+01 9.591E+00 6.496E+00 4.092E+00 2.386E+00 1.283E+00 6.337E-01 2.869E-01 1.187E-01 4.483E-02 1.541E-02 4.820E-03 1.369E-03 3.529E-04 8.248E-05 1.746E-05 3.347E-06 5.804E-07

	7.913E+01	9.104E-08
	8.376E+01	1.292E-08
	8.838E+01	1.661E-09
	9.301E+01	1.957E-10
	9.763E+01	2.249E-11
	1.023E+02	3.275E-12
	1.069E+02	9.138E-13
	1.115E+02	4.111E-13
	1.161E+02	2.068E-13
	1.208E+02	1.037E-13
	1.254E+02	5.089E-14
	1.300E+02	2.433E-14
	1.346E+02	1.133E-14
	1.393E+02	5.138E-15
	1.439E+02	2.266E-15
	1.485E+02	9.725E-16
	1.531E+02	4.057E-16
	1.578E+02	1.645E-16
	1.624E+02	6.474E-17
	1.670E+02	2.474E-17
	1.716E+02	9.182E-18
	1.763E+02	3.325E-18
	1.809E+02	1.236E-18
	1.855E+02	6.571E-19
100	0.000E+00	1.898E+01
	5.000E-03	1.540E+01
	5.500E-02	1.500E+01
	1.050E-01	1.460E+01
	1.550E-01	1.421E+01
	2.050E-01	1.381E+01
	2.550E-01	1.341E+01
	3.050E-01	1.301E+01
	3.550E-01	1.262E+01
	4.050E-01	1.222E+01
	4.550E-01	1.182E+01
	5.050E-01	1.143E+01
	5.130E+00	8.834E+00
	9.755E+00	6.587E+00
	1.438E+01	4.730E+00
	1.901E+01	3.266E+00
	2.363E+01	2.165E+00
	2.826E+01	1.377E+00
	3.288E+01	8.384E-01
	3.751E+01	4.887E-01
	4.213E+01	2.724E-01
	4.676E+01	1.451E-01
	5.138E+01	7.379E-02

	5.601E+01	3.582E-02
	6.063E+01	1.658E-02
	6.526E+01	7.321E-03
	6.988E+01	3.080E-03
	7.451E+01	1.235E-03
	7.913E+01	4.713E-04
	8.376E+01	1.713E-04
	8.838E+01	5.927E-05
	9.301E+01	1.952E-05
	9.763E+01	6.114E-06
	1.023E+02	1.822E-06
	1.069E+02	5.165E-07
	1.115E+02	1.392E-07
	1.161E+02	3.569E-08
	1.208E+02	8.704E-09
	1.254E+02	2.022E-09
	1.300E+02	4.491E-10
	1.346E+02	9.677E-11
	1.393E+02	2.116E-11
	1.439E+02	5.288E-12
	1.485E+02	1.806E-12
	1.531E+02	8.690E-13
	1.578E+02	5.038E-13
	1.624E+02	3.098E-13
	1.670E+02	1.928E-13
	1.716E+02	1.208E-13
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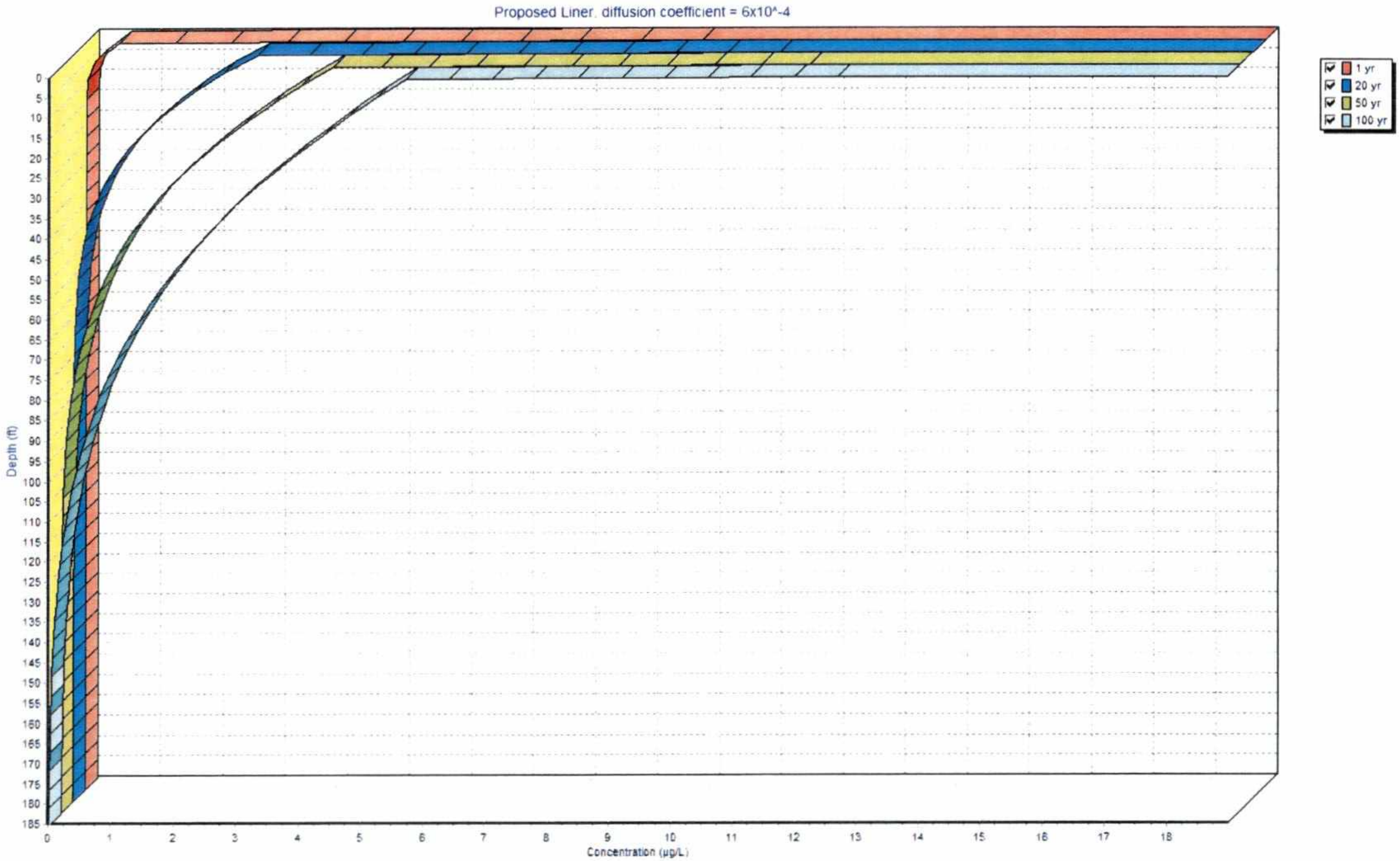
	1.855E+02	4.600E-14



Proposed liner, diffusion coefficient increased by two orders of magnitude, 100-year run.

POLLUTEv7

Version 7.11

Proposed Liner, diffusion coefficient = 6x10^-4

THE DARCY VELOCITY (Flux) THROUGH THE LAYERS Va = 1.092E-6 ft/a

Layer Properties

Layer	Thickness	Number of Sublayers	Coefficient of Hydrodynamic Dispersion	Matrix Porosity	Distributon Coefficient	Dry Density
Geomembrane	60 mil	1	2E-8 cm2/s	1	0 m3/kg	950 kg/m3
Clay Base	0.5 ft	10	6E-6 cm2/s	0.3	0 mL/g	102.9 lb/ft3
Aquitard	185 ft	10	0.0006 cm2/s	0.4	0 mL/g	102.9 lb/ft3

Boundary Conditions

Finite Mass Top Boundary

Initial Concentration = 19 µg/L
Volume of Leachate Collected = 0.0339999970082192 ft/day
Thickness of Waste = 125 ft
Waste Density = 1200 lb/ft3
Proportion of Mass = 0.001
Reference Height of Leachate = 0 m

Fixed Outflow Bottom Boundary

Landfill Length = 289.56 m
Landfill Width = 1 m
Base Thickness = 1 ft
Base Porosity = 0.3
Base Outflow Velocity = 0.002073 ft/a

Laplace Transform Parameters

TAU = 7   N = 20   SIG = 0   RNU = 2

Calculated Concentrations at Selected Times and Depths

Time yr	Depth ft	Concentration µg/L
1	0.000E+00	1.900E+01
	5.000E-03	9.930E+00
	5.500E-02	8.930E+00
	1.050E-01	7.943E+00
	1.550E-01	6.971E+00
	2.050E-01	6.012E+00
	2.550E-01	5.068E+00
	3.050E-01	4.138E+00
	3.550E-01	3.220E+00
	4.050E-01	2.314E+00
	4.550E-01	1.417E+00
	5.050E-01	5.278E-01
	5.130E+00	1.340E-01
	9.755E+00	2.199E-02
	1.438E+01	2.278E-03
	1.901E+01	1.466E-04
	2.363E+01	5.788E-06
	2.826E+01	1.391E-07
	3.288E+01	2.026E-09
	3.751E+01	1.832E-11
	4.213E+01	2.543E-13
	4.676E+01	3.907E-14
	5.138E+01	8.231E-15
	5.601E+01	1.534E-15
	6.063E+01	2.496E-16
	6.526E+01	3.532E-17
	6.988E+01	4.322E-18
	7.451E+01	4.544E-19
	7.913E+01	4.080E-20
	8.376E+01	3.105E-21
	8.838E+01	1.988E-22
	9.301E+01	1.061E-23
	9.763E+01	4.690E-25
	1.023E+02	1.706E-26
	1.069E+02	5.204E-28
	1.115E+02	1.554E-29
	1.161E+02	7.873E-31
	1.208E+02	8.075E-32

	1.254E+02	9.756E-33
	1.300E+02	1.116E-33
	1.346E+02	1.168E-34
	1.393E+02	1.113E-35
	1.439E+02	9.623E-37
	1.485E+02	7.528E-38
	1.531E+02	5.311E-39
	1.578E+02	3.368E-40
	1.624E+02	1.915E-41
	1.670E+02	9.758E-43
	1.716E+02	4.482E-44
	1.763E+02	1.913E-45
	1.809E+02	8.422E-47
	1.855E+02	6.500E-48
20	0.000E+00	1.900E+01
	5.000E-03	1.138E+01
	5.500E-02	1.053E+01
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	4.050E-01	4.619E+00
	4.550E-01	3.777E+00
	5.050E-01	2.936E+00
	5.130E+00	2.388E+00
	9.755E+00	1.910E+00
	1.438E+01	1.502E+00
	1.901E+01	1.160E+00
	2.363E+01	8.793E-01
	2.826E+01	6.540E-01
	3.288E+01	4.770E-01
	3.751E+01	3.409E-01
	4.213E+01	2.387E-01
	4.676E+01	1.637E-01
	5.138E+01	1.099E-01
	5.601E+01	7.214E-02
	6.063E+01	4.634E-02
	6.526E+01	2.910E-02
	6.988E+01	1.787E-02
	7.451E+01	1.072E-02
	7.913E+01	6.288E-03
	8.376E+01	3.601E-03
	8.838E+01	2.015E-03
	9.301E+01	1.101E-03
	9.763E+01	5.871E-04

	1.023E+02	3.057E-04
	1.069E+02	1.554E-04
	1.115E+02	7.706E-05
	1.161E+02	3.730E-05
	1.208E+02	1.761E-05
	1.254E+02	8.116E-06
	1.300E+02	3.648E-06
	1.346E+02	1.599E-06
	1.393E+02	6.839E-07
	1.439E+02	2.852E-07
	1.485E+02	1.160E-07
	1.531E+02	4.602E-08
	1.578E+02	1.780E-08
	1.624E+02	6.716E-09
	1.670E+02	2.472E-09
	1.716E+02	8.885E-10
	1.763E+02	3.143E-10
	1.809E+02	1.156E-10
	1.855E+02	6.160E-11
50	0.000E+00	1.899E+01
	5.000E-03	1.205E+01
	5.500E-02	1.128E+01
	1.050E-01	1.051E+01
	1.550E-01	9.740E+00
	2.050E-01	8.970E+00
	2.550E-01	8.200E+00
	3.050E-01	7.430E+00
	3.550E-01	6.661E+00
	4.050E-01	5.892E+00
	4.550E-01	5.124E+00
	5.050E-01	4.356E+00
	5.130E+00	3.842E+00
	9.755E+00	3.367E+00
	1.438E+01	2.931E+00
	1.901E+01	2.534E+00
	2.363E+01	2.175E+00
	2.826E+01	1.854E+00
	3.288E+01	1.569E+00
	3.751E+01	1.317E+00
	4.213E+01	1.098E+00
	4.676E+01	9.079E-01
	5.138E+01	7.449E-01
	5.601E+01	6.063E-01
	6.063E+01	4.895E-01
	6.526E+01	3.919E-01
	6.988E+01	3.112E-01
	7.451E+01	2.450E-01

	7.913E+01	1.913E-01
	8.376E+01	1.481E-01
	8.838E+01	1.136E-01
	9.301E+01	8.641E-02
	9.763E+01	6.515E-02
	1.023E+02	4.868E-02
	1.069E+02	3.604E-02
	1.115E+02	2.645E-02
	1.161E+02	1.923E-02
	1.208E+02	1.386E-02
	1.254E+02	9.892E-03
	1.300E+02	6.996E-03
	1.346E+02	4.902E-03
	1.393E+02	3.403E-03
	1.439E+02	2.340E-03
	1.485E+02	1.595E-03
	1.531E+02	1.077E-03
	1.578E+02	7.208E-04
	1.624E+02	4.794E-04
	1.670E+02	3.181E-04
	1.716E+02	2.129E-04
	1.763E+02	1.474E-04
	1.809E+02	1.108E-04
	1.855E+02	9.716E-05
100	0.000E+00	1.898E+01
	5.000E-03	1.270E+01
	5.500E-02	1.200E+01
	1.050E-01	1.130E+01
	1.550E-01	1.060E+01
	2.050E-01	9.903E+00
	2.550E-01	9.205E+00
	3.050E-01	8.507E+00
	3.550E-01	7.810E+00
	4.050E-01	7.113E+00
	4.550E-01	6.416E+00
	5.050E-01	5.719E+00
	5.130E+00	5.248E+00
	9.755E+00	4.799E+00
	1.438E+01	4.374E+00
	1.901E+01	3.974E+00
	2.363E+01	3.597E+00
	2.826E+01	3.245E+00
	3.288E+01	2.917E+00
	3.751E+01	2.612E+00
	4.213E+01	2.331E+00
	4.676E+01	2.073E+00
	5.138E+01	1.836E+00

	5.601E+01	1.620E+00
	6.063E+01	1.424E+00
	6.526E+01	1.246E+00
	6.988E+01	1.087E+00
	7.451E+01	9.440E-01
	7.913E+01	8.166E-01
	8.376E+01	7.035E-01
	8.838E+01	6.037E-01
	9.301E+01	5.158E-01
	9.763E+01	4.389E-01
	1.023E+02	3.719E-01
	1.069E+02	3.138E-01
	1.115E+02	2.636E-01
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	1.208E+02	1.838E-01
	1.254E+02	1.525E-01
	1.300E+02	1.260E-01
	1.346E+02	1.037E-01
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	1.439E+02	6.959E-02
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	1.531E+02	4.636E-02
	1.578E+02	3.792E-02
	1.624E+02	3.120E-02
	1.670E+02	2.598E-02
	1.716E+02	2.208E-02
	1.763E+02	1.935E-02
	1.809E+02	1.769E-02
	1.855E+02	1.704E-02